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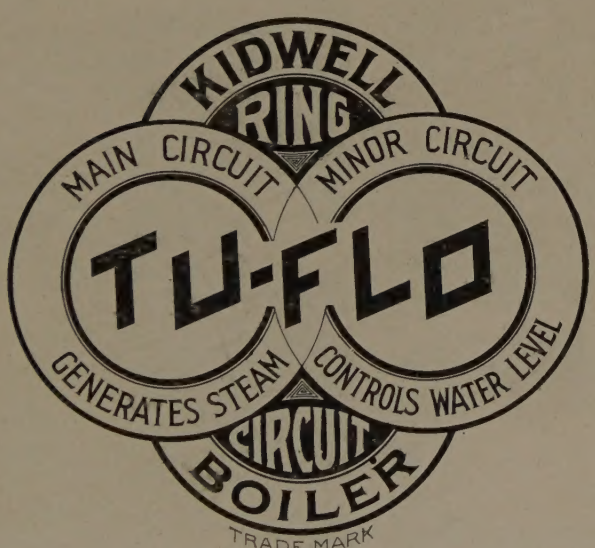
KIDWELL BOILER COMPANY

Manufacturers of

The Kidwell Two-Flow Ring Circuit Boiler, Stacks, Breechings and Sundry Boiler Appurtenances



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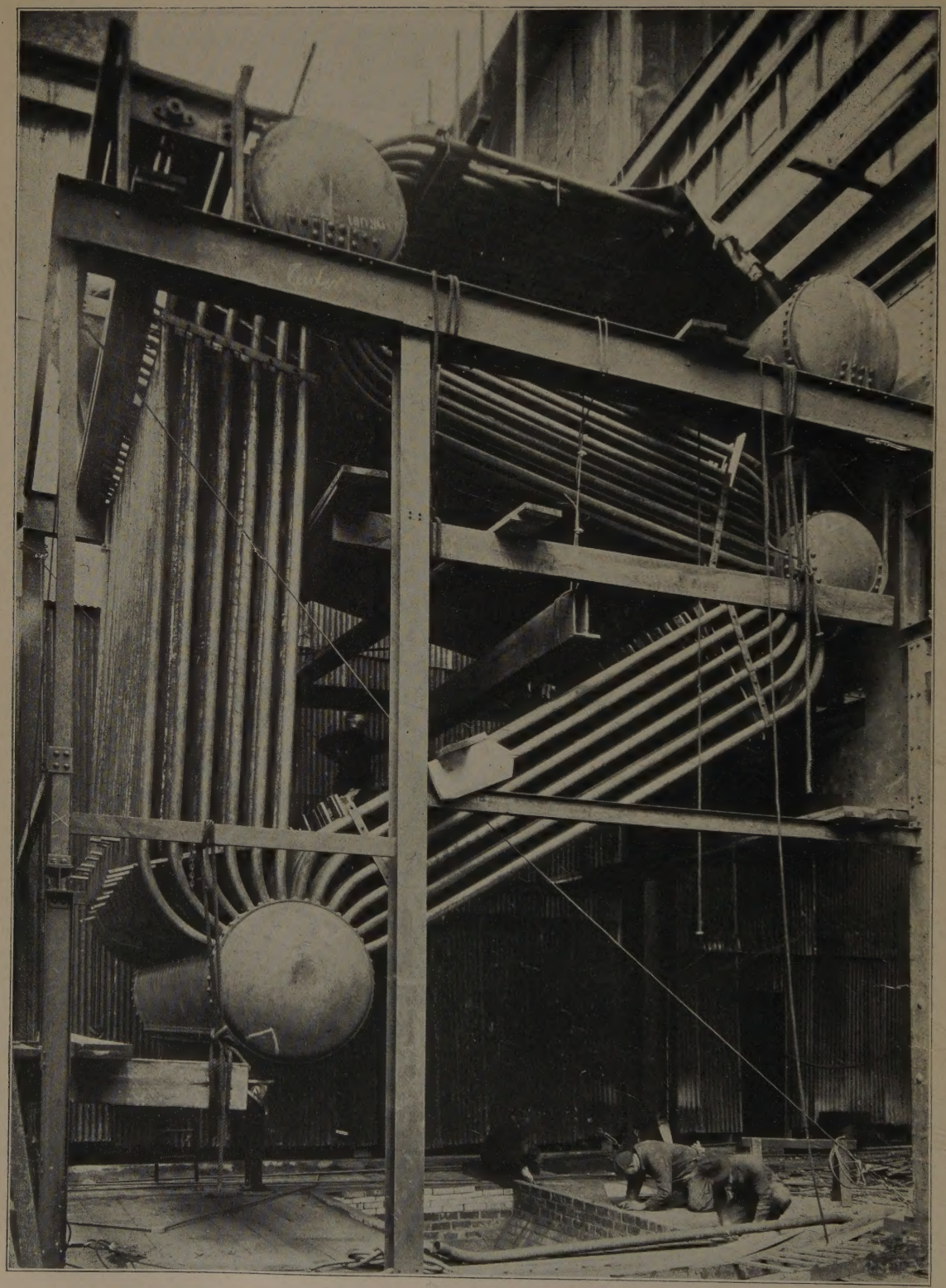

A 606 HP. BOILER IN COURSE OF ERECTION, AND FORMING PART OF 3240 HP. OF KIDWELL BOILERS OPERATED BY THE MILWAUKEE COKE & GAS CO., MILWAUKEE, WISCONSIN

The KIDWELL TWO-FLOW RING-CIRCUIT WATER TUBE BOILER

Containing

A lucid explanation of the principles underlying correct boiler design and operation, their application to boiler analysis and how they are correctly applied in the design of the Kidwell Boiler, with other information valuable to those who wish to generate more steam for less money

by

Edgar Kidwell, M. E., Ph. D.

I have what every subject of your Majesty wants, POWER!—*James Watt*
Prove all things; hold fast to that which is good.—*1 Thess., 5:21*
Felix qui potuit rerum cognoscere causas.—*Virgil, Georgics. II, 490*

Milwaukee, Wisconsin, U. S. A.
Published by Kidwell Boiler Company
1923

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The Kidwell two-flow
ring-circuit water
tube boiler

Special Notice

The publishers cordially invite those who note errors of any kind to report them so that these may be corrected in the next edition. Further, as this book is written in the interest of those who operate boilers, suggestions from engineers will be welcomed and fully considered during preparation of future editions.

KIDWELL BOILER COMPANY

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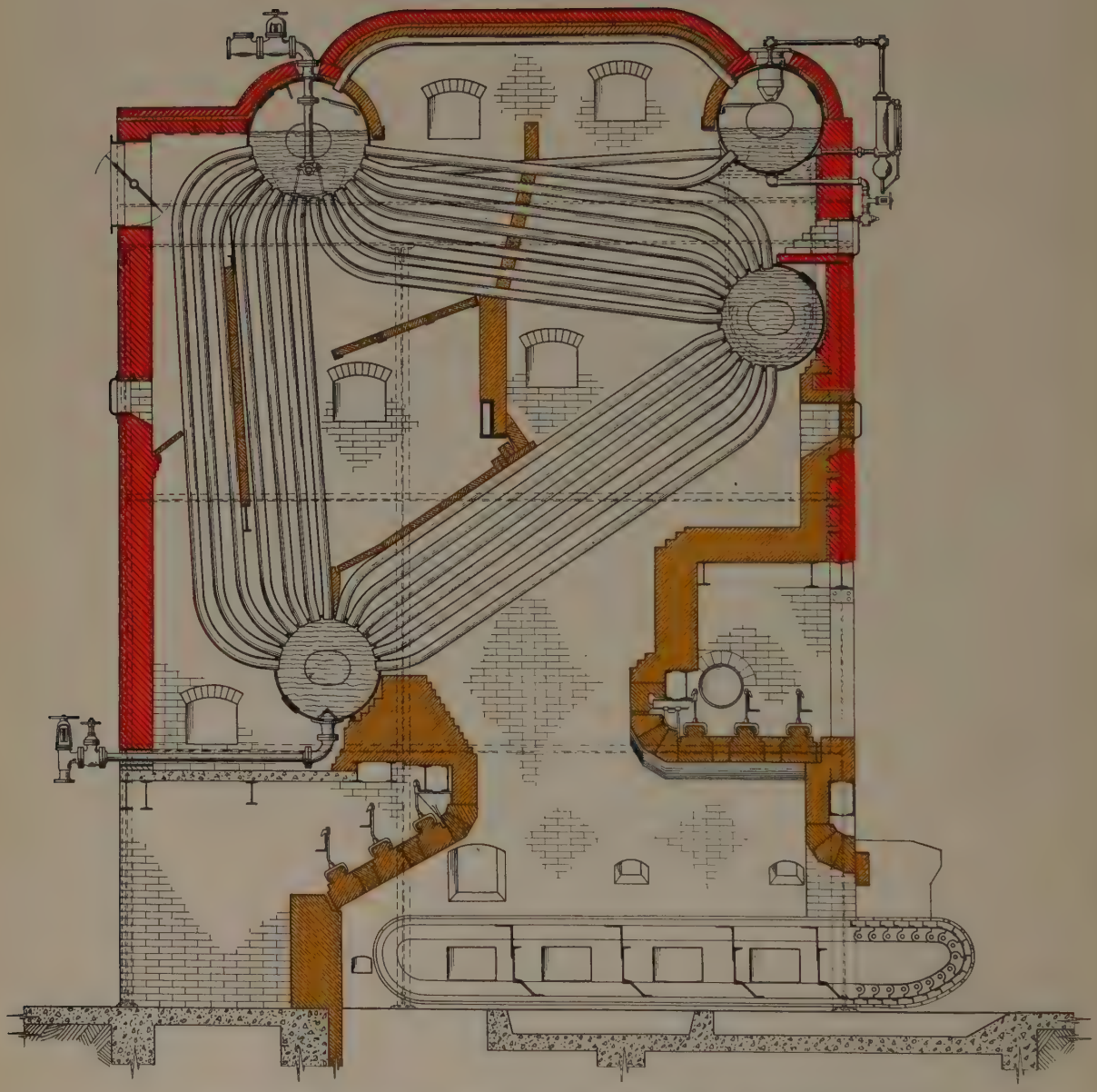
To The
Honor and
Memory of
Goldsworthy Gurney,
of Cornwall, a pioneer
investigator in the generation of
steam, who thru the divine inspiration
of genius realized more clearly than any other
man of his time or since, the necessity and effect
of rapid water circulation in boilers, and who nearly
a century ago discovered the only adequate method of-
-producing it and then gave to the world the principle of ring-
-flow circulation, this volume is reverently dedicated by
the Kidwell Boiler Company which values beyond
price the privilege of rescuing from oblivion
the work of this great and previously
unappreciated engineering genius
and of carrying to completion
the task which he
so efficiently
and nobly
began



A MODERN HIGH CAPACITY INSTALLATION FOR BURNING LOW GRADE FUELS.
TWO 505 HP. KIDWELL BOILERS WITH HARRINGTON STOKERS
AND MARION SOOT BLOWERS, FOR PETTIBONE-
MULLIKEN CO., CHICAGO, ILL.

WILLARD STARR, CHIEF ENGINEER

JOHN R. MOORE CO., CONSULTING ENGINEERS

Preface

This volume is a preliminary or advanced edition quickly gotten up to supply the insistent demand for information about the Kidwell Two-Flow Ring-Circuit boiler. To obviate delay in issuing the book, and because of the destruction by fire of every plate for the cuts, the drawings from which they were made, and other material the replacement of which was slow and tedious, the original scope of this book had to be curtailed. A more comprehensive volume will follow, hence this one makes no pretension of being complete. While the sections relating to the Kidwell Two-Flow Ring-Circuit boiler and to Stacks have necessarily had to be so written as to cover the ground quite fully, the other portions have been so curtailed that many important details are passed over hurriedly, and a great number are not even mentioned. It is therefore essential that the reader understand clearly what the scope and method of this book are if he is to derive the greatest benefit from it.

Chapter I is therefore written for the specific purpose of explaining these things, and *it should be carefully read throughout before any other part is consulted.*

To be of the utmost value a book must not only contain the desired information, but be so arranged that the reader can quickly locate everything in it. To enable this to be done not only have the Table of Contents and Index been made unusually complete, but numerous cross references have been inserted into the text. We realize that such references may in some degree divert the reader's attention from the main line of thought, yet it is believed that the advantage of the plan will more than offset this objection.

To save space the Bibliography has been confined to only the most important books which are so listed that they can easily be located in any good library. For the same reason, everything else not positively necessary has been omitted, including the usual lavish display of photographs of plants which convey no information of value. In this way room has been found for an unusual number of cuts useful in illustrating the text, and showing the sundry arrangement of Kidwell boilers equipped for stoker firing, or for burning oil, gas, etc., or utilizing waste heat, which convey information more valuable than can be got from photographs of installations. Accordingly the latter have been limited to the least number consistent with carrying out the scheme of make-up of this book.

The drawings show only a few of the possible arrangements, and the Company is prepared to submit designs with settings, number and position of baffles, and other details so disposed as to meet the requirements of any case which may be referred to it for advice.

To those from whom we have quoted we gladly acknowledge our obligation and extend our thanks for their courtesy in permitting reference to their works. To those manufacturers who have assisted us in preparing cuts showing stokers, superheaters, etc., we also express our obligations and appreciation.

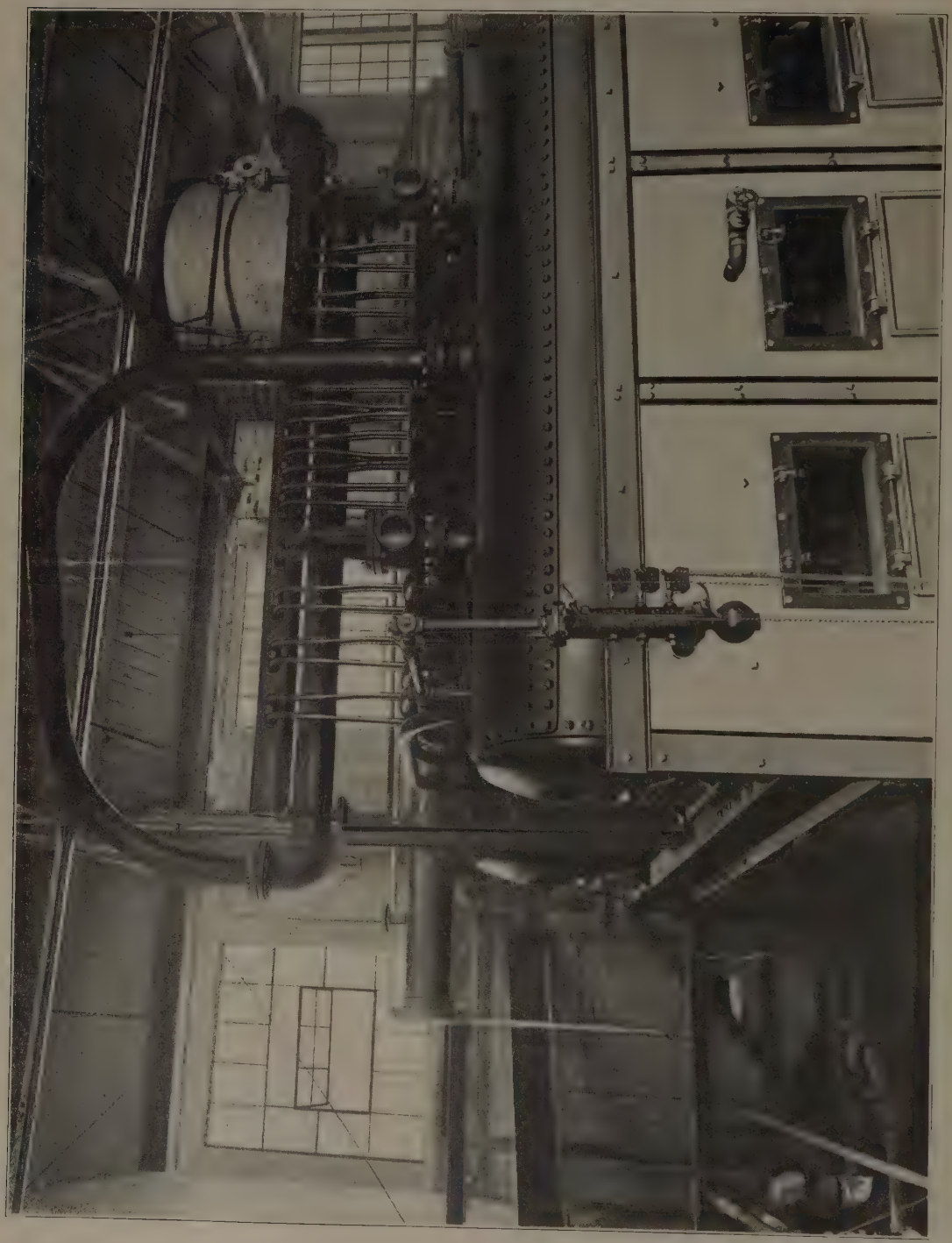
The manuscript of this book closed about February 1, 1923, but as the work was passing through the printer's hands references to later technical literature were inserted, as occasion arose, up to the time when the forms closed.

About 19 years ago the writer of these pages edited *Stirling, a Book on Steam for Engineers,* and the mechanical features, style of type, cuts, etc., met with so much favor that the same general makeup has been followed here. The resemblance stops with these features, because the general information, tables, etc., pertaining to steam, fuels, testing, etc., as given in that book have since been so generally used and republished in forms easily obtainable that it seemed preferable to omit them here, and in lieu thereof, to elucidate underlying principles and their application to an extent never before attempted in a trade publication.

This volume therefore contains many matters of vital importance which have never before appeared in print, and will not only prove every point of excellence claimed for the Kidwell Two-Flow Ring-Circuit boiler and its superiority to any other, but so equip the reader that he can intelligently dissect *any boiler design,* and thus accomplish the exact purpose for which this book was written. It is submitted to all who are interested in steam generation in the confident belief that to engineers, young and old, it will prove helpful in their exacting and noble work of generating power for the world's industries, conserving our fuel resources, and guarding human life from disaster.

Milwaukee, Wisconsin, U. S. A. May 1, 1923.

EDGAR KIDWELL



ONE OF TWO 415 HP. KIDWELL BOILERS WITH ELESCO SUPERHEATER IN COURSE OF ERECTION FOR NEW CASTLE LEATHER MFG. CO., WILMINGTON, DELAWARE

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I. The Reason For, Purpose and Plan of This Book

1. The better an article is, the more fully it welcomes and profits by thorough investigation. But to reach a just and sound verdict an investigator must have sufficient knowledge of his subject to qualify him unerringly to detect every fault as well as every merit, otherwise his final decision is worthless.

2. The main purpose of this book is to show how to generate steam at the lowest cost. To do that, boilers have to be used. Therefore, this book aims to show how good boilers can be distinguished from poor ones, and the best results be obtained from good ones. Since the publishers are offering the Kidwell Two-Flow Ring-Circuit boiler to the trade this volume naturally devotes considerable space to the design and capabilities of that boiler, but it goes far beyond that by showing how *any boiler* can be checked up as to both merits and defects, and then invites the reader to apply this knowledge to his investigation of the Kidwell boiler as compared with all others.

3. The Kidwell boiler represents a great advance over any previous design. It introduces into boiler engineering an entirely new principle which eliminates many serious deficiencies inherent in former designs, and is as effective in improving boiler operation as Watt's scheme of providing a condensing chamber separate from the engine cylinder, or Dr. Stumpf's invention of a central exhaust port for causing unaflow action were in improving steam engine performance. The introduction of this principle makes easy the attainment of results previously impossible in regular service. In consequence, this boiler can operate with safety at ratings proved to be hazardous with other designs in general use; it delivers clean and superheated steam regardless of the rate at which it is operating, and its water line is always steady and correctly shown by the glass. It has many other features of superiority, as listed in Sect. 395.

Mere assertion and reiteration of these statements prove nothing. Builders of boilers which any competent engineer sees at a glance are mere makeshifts produced to sell at a low price can and do make equally strong claims for their product. Assertion and proof are widely different things. Therefore, the purpose of this book is *to prove* that the foregoing statements are correct. *But this cannot be done unless intending purchasers thoroughly understand the technical principles underlying boiler design, construction, operation and finance, and are capable of recognizing clearly wherein any design conforms to or departs from these principles, and the relative effect and importance of such departure.* He who is unwilling to undergo the labor of acquiring such knowledge is not qualified to undertake so serious a problem as the selection of a boiler, since any error of judgment not only involves risk of a large amount of money, but jeopardy of human life as well.

4. In a court trial, not only the attorneys but the judge himself must understand the law if his decision is to be sound and just. So, in boiler matters one without the technical knowledge above defined cannot arrive at a safe choice merely from listening to salesmen or reading manufacturers' catalogs. The latter, while often artistically prepared, confine themselves to statements, explanations, and descriptions highly laudatory of the boiler in whose interest they were written, but like the argument of a flowery advocate of one side of a court case, they afford the reader no means of determining the credibility of the statements advanced, or of the relative merits or deficiencies of different boilers. That such statements are frequently inaccurate, contradictory, or adroitly worded so as to be misleading, will appear in this book. For examples, see Sects. 82, 105, 109, 236, 250, 336, 340 and others. Yet what is shown in these references is mild compared with what could be cited. For example, boiler catalogs have been issued and mailed out with the word "Patented" inserted under practically every cut, though such statement was just 100 per cent fiction. But neither the U. S. Patent laws nor Postal regulations adequately protect the public against such chicanery and its distribution through the mails.

5. Therefore, as a protection to honest boiler manufacturers, and as a matter of courtesy and fairness to the buyer and of public policy, the time has come to depart from the hackneyed form of "catalog" in which the reader's credulity is appealed to as strongly as considered safe, and to make as great an advance in this kind

of literature as the Kidwell boiler has among boilers. This plan was therefore decided upon for the present volume. As to how most effectively to carry it out, the following extracts clearly indicate the way.

6. Mr. Victor J. Azbe says in *Mechanical Engineering,* November, 1921, p. 726, that:—"It may appear to some that the boiler with its appurtenances has been developed to what might be called the limiting point; this, however, is not so. *There remains an immense field for experimental research to obtain the necessary data for boiler construction.*" The same writer in *Power Plant Efficiency* in A. S. M. E. Transactions for 1916 says:—"There are *large* and small power plants in operation today that are monuments of folly, and are wasting enormous amounts of money, *chiefly due to lack of foresight,* when designing the plant." And such lack of foresight is particularly in evidence when it comes to selection of the equipment. See Sects. 97 to 99 and 541(h).

"At least 75% of boiler plants are operated in a haphazard way. Methods of 20 years ago are used; equipment that is fairly antique is clung to as though it were a piece of Louis Quinze furniture; coal and labor are wasted with what would be insane recklessness, if it were not merely ignorance."—*Combustion,* August 1922, p. 88.

"I have come to believe that engineers neglected the boiler room for a great many years, and that in these latter years we are just coming to a realization of what may be accomplished there."—Dr. P. F. Walker, University of Kansas.

7. This is confirmed by Prof. Lucke who in his excellent *Engineering Thermodynamics,* p. 773, says:—"It seems a little curious to have to confess that the steam boiler, which has been built in one form or another for nearly 200 years, *is the least understood today of all the important structural elements of plants dealing with heat for power or other purposes, yet such is the fact.* Burning coal under and passing the furnace gases over surfaces holding boiling water looks like the simplest sort of process, and *if it made no difference how much steam could be made from a square foot of surface or from a pound of coal,* it wou'd be simple." But that it makes a great difference will clearly appear later. See Sect. 227. To cite only two items:—

8. Most buyers believe that if two boilers of different design have identical heating surface, they can operate with equal safety up to identical capacities. Such is far from being true. The maximum safe steam generating capacity of a boiler depends upon *speed of water circulation,* and how greatly this varies in the different designs will later appear. See Sects. 72 to 76, 254 to 271, and 474 to 485 for typical illustrations of this fundamental fact.

9. Those who consider first cost as the most important item often purchase boilers which prime excessively, without suspecting that from an investment standpoint a boiler which delivers superheated steam is to be preferred to one which delivers wet steam if offered gratis. See Sects. 89 to 99, also Azbe's clear-cut statement in Sect. 593. Also, wet steam is *dirty* steam. See Sect. 534.

10. Mr. L. E. Bertin, formerly Chief constructor in the French Navy, says in his splendid treatise *Marine Boilers*:—"There is a fatal misapprehension about boilers which has to be overcome. They are by no means of such simple construction as is often supposed. At present there is no problem in the design and construction of engines which approaches in difficulty those encountered in boiler design; there is no post in the engine room which necessitates so much constant care, and at times so much ability and presence of mind, as are required for the proper management of the boilers." Serious consideration of this statement is urged on those who imagine that any one who can fabricate metal is capable of designing a good boiler; or that anyone who is merely a sharp bargain driver, but lacking in the technical knowledge above defined, is qualified to select and purchase a boiler, or that anyone who can shovel coal is capable of operating and caring for such boiler. See Sects. 390 to 393. Few sentences contain such a mine of truth in so few words.

11. Rear-Admiral Geo. W. Melville, Engineer in Chief, U. S. Navy, says in *Report of "Hohenstein Boiler" and "Liquid Fuel" Boards,* Washington, 1902:—"The efficiency of the war ships of the several naval powers is simply proportionate to the efficiency of their boilers and the character of their personnel.**** *The boiler problem, however, has been unsolved.****. The value of the war ships of the different naval powers can be measured by the efficiency and endurance of the steam generator installed in

the vessel. This fact may not be appreciated in its fullness at the present time, but the experience of the coming 5 years will conclusively show that in coming naval conflicts the question of victory may be quite as much dependent upon *the battle of the boilers as the contest between the guns.*" This statement from a world's authority deserves consideration from those who imagine that "all boilers are alike," or that the way to buy boilers is to select something simply because offered at a low price.

12. The disastrous consequences of entrusting boiler design to those who are not qualified are reflected in the casualty lists of Insurance Companies. Yet purchasers lull themselves into the belief that if a design can pass inspection and secure an insurance certificate *it is de facto* safe. That this is not true is shown in this book. There is no boiler code so written that compliance with its requirements will *guarantee* a boiler to be safe. Examples:—The dangers incident to diversity of water line as shown in Sects. 60, 61, 296 to 299, 352 to 358 and others; the liability of mud drum nipples loosening and causing a wreck as shown in Sect. 240; the danger of plugging over-comer tubes as shown in Sect. 357; the liability of overheating and exploding a drum *assumed* to contain water, while in fact it does not, as shown in Sects. 298 to 300, 309 and 310; the menace of low water due to deficient water endurance surface, as illustrated by the explosion quoted in Sect. 235(b); the weakness of large flat tube sheets, regardless of how they may be stayed, as shown in Sects. 282 and 283; the greater liability of some types over others as to burning tubes because of deposit of scale on tubes over the fire, as shown in Sects. 119 to 122 and 250 to 253; the limitation of capacity due to steam locking of tubes, as shown in Sects. 72 to 77 and 249 to 271, and numerous other features which might be cited, are neither covered nor guarded against by any boiler code. The reason is that codes cover mostly *constructive details as to material and workmanship,* but concern themselves very little with how the boiler functions when in use. It is therefore necessary for a purchaser to locate such deficiencies for himself, and be guided accordingly, until such time as laws are enacted which will bar from the market all designs in which such deficiencies exist. This will come in time, and as indicating the trend in that direction the following from the preface of *Nystrom's Mechanics,* 19th edition, by Prof. Wm. D. Marks, is pertinent:

"A single branch of mechanical engineering may require half a lifetime of study and experience before the engineer is competent to undertake designing in it. The writer cannot too strongly call the attention of engineers to the deplorable results of over-confidence and superficial reasoning. It would be far better that our laws should hold him a criminal who, through ignorance or dishonest pretension of knowledge, makes blunders resulting in the loss of life and property, than that the present loose ideas as to the dignity and responsibility of an engineer's position and work should prevail. * * * * It makes no difference what the *intention* or *wish* of the designer may be, matter and force blindly and inevitably follow the laws of nature with certainty and precision. The designer must learn these laws, and *all of them* that affect the particular case he has, before he can effect a safe and general solution." This is confirmed by Dwight's statement in Sect. 373, and practical proof of it is shown throughout this book. For a typical case see Sects. 353 to 364.

13. As showing why boilers grossly deficient in design still find many purchasers, and why the inaccuracies and shortcomings of the conventional boiler publication are not realized, we next quote an authority whose long experience and proved ability as an investigator entitle his opinion to the utmost weight. Mr. Henry Kreisinger says:—"The main reason for tardiness in boiler improvement probably lies in the reluctance of educated engineers to do the dirty and disagreeable work involved in boiler tests."—Bulletin 18, Bureau of Mines, *The Transmission of Heat into Steam Boilers,* p. 13.

14. As evidencing how many whose duty *obligates* them to acquire concerning boilers enough knowledge at least to prevent themselves from being dangerous to others, shirk the task, even when "the dirty and disagreeable work" is wanting, the following by Admiral Melville, quoted in Sect. 11, is illuminating:—"One must have experience in the operation of a modern marine boiler to appreciate the intelligence, skill, and care that must be devoted in keeping it in a state of efficiency. The boilers are the lungs of a vessel, although this fact is not generally

understood. *It was not many years ago when a naval officer of high rank spoke of the boilers as 'the steam tanks in the bottom of the ship,' it being probably his impression that these tanks could be tapped like a gasometer, and it was the fault of the firemen if the boiler output was not sufficient at all times.*" Every field engineer constantly encounters similar incredible ignorance.

15. The main reason why boilers wrong in principle and far behind the present state of the art of boiler designing are still bought in large quantities is a similar reluctance on the part of the buyers to do the hard mental labor necessary for acquiring a correct knowledge of the advances that have been made and incorporated into improved designs now on the market. See Sects. 277 to 280. This is the more remarkable because in the selection of prime movers the procedure has been radically different. Improvement has been welcomed, and adopted as soon as known. This is because, as above indicated by Bertin, such equipment is easy to understand, and its performance can be readily measured. But as pointed out by Prof. Lucke in Sect. 7, *this is not true of boilers,* and the acquisition of adequate knowledge concerning them is a far more difficult problem, therefore buyers act more frequently on custom or precedent than on actual knowledge.

16. Yet the buyer is not greatly to blame for this, because hitherto there has been no book available in which the essentials are discussed sufficiently to give a good working knowledge of the subject, and few buyers have the time or facilities to gather such information, which is scattered throughout the world's engineering literature. Nor is all essential information found even there. Thus, such literature shows nothing as to the inherent deficiencies of header types due to their being an evolution of an originally wrong idea, nor does it show that the U. S. Navy has at last realized this and modified its procedure in accordance therewith by adopting curved tube boilers for practically all important vessels laid down during the last four years.

17. Second to no other consideration whatever is the fact that improvement in boiler performance conserves the fuel supply and redounds to the public welfare. It is therefore a matter of public welfare that the widest possible publicity be given to all information which shows how boilers can be made to do more and better work with less fuel and greater safety to those who operate them. Or in other words, how good boilers may be detected and adopted, and poor ones be weeded out. The U. S. Government has officially sanctioned this view by authorizing that splendid series of investigations on fuels, combustion and boiler performance conducted by the Bureau of Mines. No work of greater importance to boiler operators has ever been undertaken, and it should be observed here that power users everywhere should neglect no opportunity of testifying to the value of that work, and of urging that ample means be provided for continuing it and publishing the results without delay.

The work of the Bureau has been freely utilized in this volume, but as the original publications cover a vast range and go into detail to an extent necessary to serve the needs of investigators and specialists, they cannot meet the requirements of the busy engineer in active practise, or purchaser who needs information reduced to compact form and applying solely to the problem of how to dissect and judge a boiler design.

18. Hence there is today an urgent need of an *engineering* volume in which the principles underlying boiler design and operation are so clearly explained that any one with reasonable diligence can master it and thus be capable of making his own analysis of a boiler, and of drawing a correct conclusion as to its merits or deficiencies. Such a work must be strictly *up to the minute, and written with reference to technical truth only, and without any regard to whom it favors or hurts.* That such volume has not previously appeared is not strange. Waiving the important item of finding one who is qualified to produce it, the obvious fact is that the only manufacturer who could, without jeopardy to his business, venture on the publication of such volume is one whose boiler is so technically correct in design that a cold and impartial scientifically correct exposition of the principles underlying the subject cannot then be turned against him and used to prove wherein his own boiler is deficient.

19. The Kidwell Two-Flow Ring-Circuit boiler is *technically correct in design,* hence stands ready to meet the above stated test. It welcomes close analysis and investigation, and the more exhaustive these are the better its

merits will be understood. Therefore the present volume, within the limits possible in this advanced edition, is written on precisely the lines above laid down. In the earlier chapters the essentials are gradually developed, explained and illustrated so as to be easily understood. In their presentation the aim has been to be accurate and as thorough as the space available permits. We have kept in mind the famous maxim of Hipprocates, written over 2350 years ago, that:—"Life is short, and Art long; the occasion fleeting; experience fallacious, and judgment difficult," hence have not only explained the underlying principles, but to save the reader's time and help him to reach a sound conclusion we have placed before him the experience and judgment of others whose testimony appears worthy of belief.

This is a technical book. It therefore cannot be read and absorbed as if it were a romance. Yet even in this we have aided the reader by sparing no labor to convey the information in clear, terse, correct and idiomatic English readily understood by all. A long word has never been used when a short one would qualify. Yet here too applies forcibly the declaration of Euclid that:—"There is no royal road to learning," hence it is beyond our powers to produce a worth while book on boilers that can be mastered without labor.

And for the further convenience of the reader we have not hesitated to violate some of the most sacred canons of the book maker's art, since we have placed *on the right hand page* all tables or diagrams whose width is equal to page height, because when so placed reference to and use of the material is easier than if placed in the conventional way.

20. To give facility in applying the principles as developed we have made a brief analysis of several types of boilers. If anyone complains that more attention has been paid to deficiencies than to merits, the answer is that a searcher of titles or a medical examiner who understands his business proceeds on precisely similar lines, since by recording the defects he can consider as merits all items not so listed; his duty is to decide whether the summation of defects is such as to condemn the title or reject the candidate, and it is precisely so with boilers. It is a poor cause which cannot face the truth. The course we have followed is the only one which will enable buyers to ascertain what they should know. That it is sound is shown by the following from *Mining and Metallurgy,* November 1921, p. 2. A report on *Elimination of Waste in Industry* had been presented, and some objected that it revealed things which had better be concealed. The editor's reply follows:—"The report has been severely criticised from the view point that it was not best to publish matter calling attention to deficiency in the management and the use of capital and that the results may be improperly used. *If the report represents facts, is it not better to face these facts?* All of those who have carefully studied our industrial problems must have appreciated that we were only beginners and that we have much to learn of economies in production. In the last generation we have suddenly rushed into a metal age and have developed an industrial condition that is simply startling. *That mistakes were made, was to be expected, but the sooner we face these mistakes and find out why they were made the more progress we shall make.*"

21. Therefore the only question is whether anything pointed out as a deficiency is not correctly stated, and that is submitted to the judgment of the reader, who will not fail to notice that, to a degree not found in any similar work, due credit has been given to many great men who were pioneers in their respective lines, and whose labors the world enjoys today, while the men themselves have been forgotten because others have not done them justice. In the dedication we have sought to revive and keep green the memory of a master mind not less deserving of a niche in the Temple of Fame than Watt, Stephenson, Fulton, Corliss, Ericsson and Parsons.

22. The chapter on the Kidwell Two-Flow Ring-Circuit boiler was written not as an exercise in framing laudatory statements, but to *prove each assertion made,* and in this respect it will be found radically different from the usual literature of the day. That this boiler does in operation accomplish exactly what is herein set forth is a demonstrated fact whose proof the reader can obtain, therefore this chapter is submitted to those competent to judge, in the belief that it will not be found wanting.

23. Readers will notice that we have always put the buyer's interest first, and have told him how to produce the maximum quantity of steam from the fewest possible boilers. To those who

object that such advice is equivalent to shrinking the possible volume of boiler business, even to the advantage of stoker builders, our reply is that this book is written on *sound engineering and financial principles and that not one line in it is devoted to the purpose of leading anyone to buy boiler capacity which he does not need!* This book reflects the policy of this Company in its relation to its clients, and if such policy is unusual that does not deter us. We want the public to *know the facts*. To those who dissent we commend the opinion of President Lincoln that "Public sentiment is everything; with it nothing can fail; without it nothing can succeed." The Kidwell boiler can and does return to the buyer more steam generating capacity per dollar invested than can be done by any other, *and that is why this boiler is on the market today*. It was not taken up merely to start a superfluous industry, but to fill a want which no other design can supply. Therefore, with such capacity available, it is sound engineering and financing to show the buyer how to profit by this fact. If it be urged that this is unnecessary altruism our answer is that it is simply square dealing, and is what we purpose to do. We are in hearty accord with the statement of Mr. Daniel Willard quoted in Sect. 279, and purpose to assist our clients in carrying it out.

24. A feature second in importance to none is that we have aimed to bring out sharply and vividly the greatest deficiency in boiler design up to the present time, which is that it has so largely been evolved by the *mechanic*, as distinguished from the *physicist* and *chemist*, so that until such scientists cooperate at every step with the mechanical constructor no important advance in design will be forthcoming. The Kidwell Two-Flow Ring-Circuit boiler illustrates this. Its great advantage over previous designs is due to the fact that the *natural physical laws controlling steam generation were worked out first*, and the boiler was then so designed as to *conform to those laws*, as shown in Sect. 396 and following. It is this fact which enables this boiler to produce results previously unobtainable in regular operation.

This reverses the usual procedure by which some design which has done fair work is claimed to be perfect, and its exploiters peg away at it for decades without introducing any improvement in principle. Like the famous bed of Procrustes it is *fixed beyond change*, so that the buyers' requirements are shortened or stretched to *suit the design*, as shown in Sects. 249 and 471. This is greatly to the advantage of the boiler builder and seller, but it is even more to the disadvantage of *the user*, and is fatal to progress in boiler development.

A Spark from the Furnace. No. 1

Through the courtesy of *The Associated Newspapers*, New York, we are permitted to republish the following pertinent article:

Being Sure—By John Blake

"I just had to let a man go," said the head of a nation-wide business establishment to the writer recently. "He looked like a million dollars, he had a winning personality, he was willing to do anything you asked him to do and he was personally ambitious. But he didn't know anything accurately. He was never sure.

"When I asked him the name of a merchant in Duluth who was one of our customers, he would answer right off the reel and usually answer wrong. When I asked him the name of the general traffic manager of a railroad he would give me the name of one of the vice-presidents.

"If I asked the output of a certain factory, he would tell me without hesitation and miss it by a couple of hundred thousand tons. One of his troubles lay in those ready answers. He made them so glibly and with such an air of assurance that I got to depending on him. He had traveled all over the country and sold a lot of goods. It never occured to me that he didn't know what he was talking about.

"So I made him an executive at a big salary. He cost us more money than I like to think about in the first two months he was here. Now he is gone. I wouldn't even send him back on the road, good salesman as he was, because I can't afford to have a man working for us who is not absolutely trustworthy."

Men of this kind are very common in business. But they never remain long in important places. They are always glib but they are never sure. It is too much trouble for them to get accurate knowledge as they go along. They do well enough in minor places. Often their pleasant personalities conceal a vast deal of slovenly thinking and work.

But the minute they are given important places, they reveal the fact that they know nothing accurately. And the worst possible handicap to any business is the man who has no accurate knowledge of the subject with which he is dealing.

☞**Moral:—When buying boilers be sure of what you are getting and what it will do for you. This book shows you how. Read Sects. 97, 393, and 583 to 589.**

II. General Principles Underlying Correct Boiler Design and Operation

25. The last three decades of steam power plant development have proved the following facts:—

(a) That for units of 150 HP. or larger a properly designed water tube boiler is the only type which can successfully meet the severe requirements of today as to high pressure and great capacity, hence no other is now considered by competent engineers for a plant of any magnitude designed to produce maximum results at minimum operating cost. Even the Navies of the World, including that of the United States, which formerly were unyielding partisans for shell types of boiler, have now adopted water tube boilers almost exclusively.

(b) That to obviate a large initial investment in equipment which is non-productive during a considerable portion of time it is necessary to use boilers which can be run at high ratings without increasing the operating troubles, or decreasing the fuel efficiency more than slightly, or the safety to any degree whatever. "The boiler that is best suited for power plant work, in addition to being economical, should be capable of being driven with clean feed water to a capacity limited only by the amount of coal that can be burned in the furnace."—D. S. Jacobus in *The Generation of Power, Journal of Franklin Institute,* December, 1910. "Dr. Jacobus reiterated that, in his opinion, where there are peak load periods the amount of heating surface per kilowatt output will be *decreased instead of increased as the art advances."—Ibid.* The same writer also states in *Boiler and Furnace Economy,* in *Mechanical Engineering,* December 1921, that "boilers are being run at higher and higher capacities in our modern power plants and the tendency seems to be upward rather than downward." Also see Sects. 183 to 186, and statements of Messrs. Azbe in Sect. 495, and Martin in Sect. 499.

(c) That to comply with these requirements a boiler must have a water circulation which is *definite and unreversible* in direction, and sufficiently rapid to scrub off and sweep away from the boiler tube surface each and every steam bubble as fast as it is formed, so that the tube surfaces are *always water-cooled* at any rating at which the boiler is to be operated. See Sects. 35, 36, 59, 120 and 247 to 255.

(d) That the maximum rating at which any boiler can be operated with safety and durability must necessarily be below that at which the steam bubbles fail to be detached as above specified, since at and above that point the tubes become locked or pocketed with steam and rapidly overheat, blister, bulge and rupture. See Sects. 35 to 43.

(e) That the volume of water in the boiler shall be great enough to prevent a large drop of pressure when there is a sudden increase in the demand for steam, but not great enough to prevent getting up steam fast enough to enable the boiler to be cut into the line quickly, either from a cold state or when the fires are banked. See Sects. 183 to 186. For comfort in operation and safety against low water it is *absolutely essential* that the water volume be so arranged as *always to have ample and practically constant water endurance surface.* See Sect. 78 for definition of this important term.

(f) That operating difficulties, liability of burning the drum plates and of pulling water over into the steam mains, increase in proportion as the water line is more fluctuating, unsteady and indefinite, and that the fuel efficiency is also reduced thereby, (see Sect. 511), hence there has long been an urgent demand for a boiler which maintains a positive and practically steady water line under all fluctuations of load, though previously no such design had appeared. See Sects. 58 to 66, 298 to 300 and 351 to 357.

(g) That the common practise of valuing a boiler because of its fuel efficiency at some low rating and under ideal conditions is futile and misleading, because what is wanted is the highest *average* fuel efficiency during the *entire run between cleaning periods,* and at the average rating to be developed during such run, and under the regular operating conditions as to fuel, feed, etc., during that run. See Sects. 109 to 112 and Fig. 46.

(h) That fuel efficiency is *secondary to the efficiency of Capital,* which involves the factors of safety, depreciation, repairs, frequency of and the time and expense of cleaning, quality of steam, ruggedness in operation or the reverse, and numerous other factors as stated in Sects. 105 and 140. "The true measure of

efficiency of a boiler installation, in the last analysis, is its cost divided by its thermal ability to convert heat into steam."—V. Z. Caracristi in *Combustion,* August 1922.

(i) That the consideration paramount to all others is that of *dependability,* or the ability of the boiler to remain in service the greatest number of hours per year, meet all demands upon it without danger of stoppage or to operatives, respond readily to overloads in emergencies, and cause the least loss of time and expense for repairs. *Unless a boiler can do all this it is an unattractive investment, regardless of the price at which it is sold, or its fuel efficiency, or any other seeming advantage.* Note Hutton's statement in Sect. 547, and the following from an editorial in *Power,* May 23, 1922, p. 826,—"There is at present a decided inclination among power users to adopt the slogan *'Reliability first, Ecenomy second,'* with a realization that this means, everything considered, greater saving in dollars and cents."

(j) That wet steam driving engines or turbines causes a large operating loss, and therefore any boiler which delivers steam containing *any* content of moisture is seriously deficient, hence should *not now be used!* See Sects. 89 to 99. It also carries mud into superheaters, thus reducing their efficiency and durability; into engines, which greatly increases the wear of the rubbing parts; and into containers used in processes, where its evil effects are often serious. See Sects. 101 and 534.

(k) That large furnace volume and means of insuring perfect combustion in the furnace with the least excess of air and of transmitting the heat to the boiler with the least loss, are equal in importance to the design of the pressure vessel which absorbs the heat and generates the steam. See Sects. 156 to 176.

(l) That the real problem of the boiler buyer is to obtain the correct answer to the question "What boiler, from the day I buy it until it goes into the scrap pile, will return to me the largest earning on every dollar I spend in buying, installing, operating, and maintaining it and the other equipment I have to install as essential to its operation?" See Sects. 105 to 112, 592, 593 and the analyses of boilers starting with Sect. 228.

(m) That previously no book has been written for the specific purpose of placing before the buyer the information necessary for carrying out the method above formulated.

Hence the present volume, as explained in Chapter I.

26. A large treatise would be necessary for an adequate explanation of all the principles underlying the above statements, and presentation of the experimental evidence necessary to a complete demonstration of their correctness, hence all that will be attempted here is a brief explanation sufficient to enable the reader to grasp the main facts, and to understand their consequence so that he can apply them when selecting a boiler. But sufficient references are given to enable anyone so disposed to carry the investigation farther than here possible.

27. Feasibility of High Boiler Ratings. Breckenridge and associates (p. 178 of Bulletin 325, U. S. Geological Survey,) as the result of an exhaustive study of 400 boiler tests say:—"The authors see no reason why boilers can not be constructed and probably operated with entire satisfaction, which will produce about *10 times* the amount of steam now obtained per sq. ft. of heating surface, and with no difficulty in obtaining dry steam. The efficiency from coal to steam should easily be made considerably higher than that of a good performance of today. *Such a plant would require only a fraction of the present investment in steam plants, buildings,* and real estate. Perry states in his book, *The Steam Engine and Gas and Oil Engines,* that he thinks boilers should be made to do 10 and possible 20 times the work they do at present." Kreisinger and Barkley on p. 24 (last paragraph) of Technical Paper 114, U. S. Bureau of Mines, *Heat Transmission Through Boiler Tubes,* show that from 2 to 2.8 boiler HP. have been safely generated per sq. ft. of heating surface.

28. Kreisinger and Ray, Bulletin 18, U. S. Bureau of Mines, *The Transmission of Heat in Steam Boilers,* p. 136, state:—"Considering the high heat conductivity of metals, there is no reason why boilers could not be made to generate steam at 3 or 4 times the rate that they do at present by simply forcing about 3 or 4 times the weight of gas over their heating surfaces. *This may be considered a conservative statement, as much higher rates are possible and have been obtained."* On p. 140 of the same book they state:—"The obstacles in the way of higher boiler capacities are superficial, and if the great advantage in the reduction of the first cost of a boiler plant is considered, it seems that the high capacity boiler is *bound to come*

in the near future. This reduction in boiler plant will give steam power a greater advantage over gas power in large central stations."

29. That engineers who have made a specialty of boiler operation realize that ratings far higher than now used will soon be common is forecasted by Mr. David Moffatt Meyers who says:—"I believe we may look forward to the application of surface combustion with coal fired boilers, and that within a reasonable period we shall see boilers operated at 1,000% rating, based on the nominal rating of 10 sq. ft. of surface per HP., as used at present."—*National Engineer,* November 1921, p. 567. By "surface combustion" this writer refers to a method developed principally by Prof. W. A. Bone of England, and described in Bulletin 18, as above cited, p. 165. It has not yet come into use for large boilers.

But the same result will inevitably follow from the rapid development and adoption of methods of burning pulverized coal, for which see Sect. 189. This permits the easy operation of boilers at ratings impracticable with stokers particularly for constant runs, and already this Company is figuring on installations to operate at 400% of rating as long as desired, when fired in this way.

30. Why Such Ratings are Not Now Used. There are five reasons:—(a) At such high ratings the flue gas temperature is too high for good fuel efficiency unless an economizer be installed. This is not necessarily so, however, when boilers are operated at from 2 to 4 times the conventional rating, which it is desirable and profitable to do during peak loads and emergencies. See Sects. 183 to 186, and 490 to 499. (b) This would reduce the present volume of boiler business, and few makers are altruistic enough to do that just to help the boiler purchaser to reduce his investment. (c) The main reason is that boilers as usually designed cannot live under high ratings because their tubes overheat, distort and burst. See Sects. 249 to 256. (d) Steaming at such ratings produces in previous designs of boilers an unstable and distorted water line that is excessively troublesome to the operator, and frequently is highly dangerous. See Sects. 60, 61, 266 to 277, 296 to 299, 354 to 356, and 366. (e) It also frequently causes excessive priming. See Sects. 235(b), 236, 288, 298, 299, 304 to 310, 356, 367, etc. The matter is thus summed up in *National Engineer,* November 1921, p. 570:—"Priming, unstable water line and impaired circulation must be guarded against by such *changes in design* as each particular make of boiler is found to require when forced beyond its normal capacity," or normal rating.

31. How Much Heat Can a Tube Transmit with Safety? This question is answered in Technical Paper 114, Bureau of Mines, above cited, on p. 25 of which is a summary of deductions wherein it is shown "that the temperature of the tube is affected very little by the temperature of the hot gases, but follows the temperature of the boiler water. **** This fact indicates that a boiler tube can transmit very easily all the heat that can ever be imparted to it by the hot gases, and that as long as the tubes are kept free from scale, oil and *other deposit and filled with water* it is impossible to overheat the tubes, no matter how hard the boiler is worked." This is confirmed on p. 8 of catalog of Howden Boiler Co., Glasgow, as follows:—"It is impossible to injure fairly clean plating over the hottest possible fire under highest forced draught *if the steam globules immediately after formation arise upwards from the plate surface to the steam space and are replaced by the surrounding particles of water not yet evaporated.* **** The few square feet area of the crown plate of the fire box of an express locomotive boiler above the fire under a forced draught of 9 or 10 inches water gauge, and consuming from 100 to 150 lbs. of fuel per sq. ft. of grate per hour, producing an almost white heat approaching 3,000° Fah., are not in the slightest degree injured by this tense heat, because the steam globules immediately rise into the steam space and are replaced by the water."

"One other fundamental factor is also important. The temperature of the steel tubes forming the boiler heating surface is always within a very few degrees of the water temperature within the boiler. A rapid calculation indicates that a boiler can be operated at 1,000 % of rating (it has been done), and the temperature of the outside of the tube will not be more than 50 deg. higher than the water temperature; and if the tube is clean on the water side, there may be only 20 deg. difference. Adding 50 deg. to the temperature corresponding to 350 lb. per sq. in. gauge still leaves a nice margin of safety below the danger temperature. In fact steel is usually stronger at that temperature than at 70 deg. F."

This citation is from an article by F. C. Hobbs in *Power,* Dec. 6, 1921, p. 902.

32. A striking confirmation of the fact that the material separating the hot gas and the water is not injured by the heat, just so long as water covers all of the inner surface, is that *water can be boiled in a paper bag* without injury to the bag provided the steam bubbles are detached as quickly as formed. The same applies to glass test tubes used in the laboratory.

33. Oil In a Boiler is due to carelessness which is not to be charged against the boiler. Scale is due to the character of the water and is not wholly chargeable to the boiler, though as proved in Sects. 119 to 122 the design of the boiler largely determines whether the scale is deposited where it does the least harm, or on those surfaces exposed to high temperature where its consequences are most serious. Header types of boilers are particularly lacking in this respect (Sect. 120), and that their most energetic advocates realize this weakness is evident from the energy with which they insist on *clean* feed water. See remarks of Dr. Jacobus, in Sects. 251 and 252. While good feed water is highly desirable, *it is not always available,* hence it is important that every boiler should be able to operate with safety if it be necessary to feed it with poor water during emergencies.

34. The "other deposit" above referred to is *steam itself!* Steam has small conductivity for heat, (see Durston's experiments, Sect. 43), hence if contained in a tube exposed to high temperature that tube will quickly overheat unless the steam travels at a considerable velocity, as in a superheater. A condition as shown in Fig. 1 will invariably overheat the top of the tube, cause it to expand faster than the bottom, and buckle upwards as in Fig. 45. This result is hastened if a hot tile rests on the tube, as shown in Sect. 264.

35. Necessity of Water Speed, or Circulation. The only way to prevent steam from adhering to the boiler tube surface or gathering in volume in some part of the tube is to *remove it as fast as formed,* and in a stationary boiler the only agent available for doing this is the water itself. The water must travel at a speed sufficient to detach from the tube surface each and every steam bubble *as fast as formed, and sweep it out of the tube and into the steam space.* Since the higher the rating at which the boiler is operating the greater the number of steam bubbles formed, the greater the speed of the water must be. Breckenridge, p. 129 of Bulletin 325 above cited, says:—"The velocity of circulation of water in the boiler is equal in importance to the velocity of the gases on the outside of the heating surface. The amount of steam formed increases directly with the rate

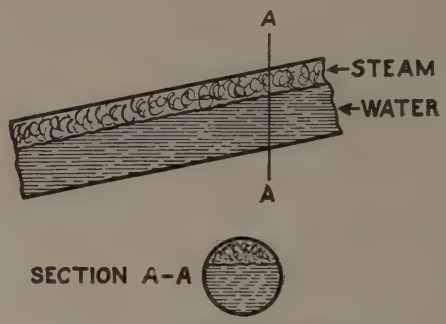


FIG. 1. A STEAM LOCKED TUBE

of heat transmission, *and if the scrubbing action of the circulation of water is insufficient to remove it from the heating surface the resistance due to the layer of steam formed will rise with the rate of making steam. Lack of adequate circulation of water in a boiler is a check to capacity.* The fact is becoming well known that small automobile boilers are making steam 10 to 20 (or even more) times as fast per unit of heating surface as stationary boilers in power plants, and at better efficiency.* This increased rate of steaming is attained purely by *high velocity of water and steam circulation over the heating surface."* See Powles' comment on Gurney's work in Sect. 346.

*This is largely due to the vibration of the vehicle when in motion, which shakes the bubbles loose from the tube surface and thus materially assists the circulation. The same effect is secured in locomotives, and it is a well known fact that when a boiler from a locomotive is installed in a stationary plant it cannot produce any such amount of steam as it did when on the rails. The same reasoning also applies to marine boilers, and explains why certain marine designs do not steam as well in land installations. "Circulation is assisted by agitation of the liquid, by stirring, or shaking, which probably accounts for the high evaporative efficiency of many locomotive boilers."—Hutton, *Steam Boiler Construction,* p. 100.

T. V. Blomquist of Sweden utilized this principle by producing a boiler in which "the steam is generated in rapidly revolving tubes," and this has evaporated as high as 100 lbs. of water per sq. ft. of heating surface per hour at gauge pressures of 900 lbs. or higher. See p. 238 of *Power,* Feb. 13, 1923.

Stromeyer, *Marine Boiler Management and Construction,* p. 119 confirms the necessity of such scrubbing action thus:—"In water tube boilers circulation is of importance because the steam bubbles have to be carried away" from the generating surface as fast as formed.

Hutton, *Steam Boiler Construction,* p. 100, says:—"Circulation is a more important factor in the distribution of heat than either the nature or thickness of the metal through which the heat is transmitted. The quantity of heat which can be transmitted to water in a given time is limited only by the rate at which it can be carried away from the heating surface by the convection currents."

"On the water side it is as necessary to get the heated particles of water (steam) away from the heating surface as it is on the fire side to get the gases that have been cooled by contact with the cold walls away from them."—Bertin and Robertson's *Marine Boilers,* p. 197.

"A constant and free circulation of water is one of the most important requirements in the design of a water tube boiler. In this vital feature many boilers are deficient."—Catalog of E. Keeler Co., 1912, p. 25.

"The failure of many of the early water tube boilers was principally due to bad circulation." —Powles, *Steam Boilers,* p. 225.

Steam Boiler Engineering, published by Heine Safety Boiler Co., (i. e., *Helios.* 27th Edition) p. 568, states that free and definite circulation is essential in boilers which are suddenly called upon to carry heavy loads, *because the water must get into motion quickly.* This is confirmed by Hutton, *Steam Boiler Construction,* p. 425, thus:—"Steam cannot be raised quickly in boilers with sluggish circulation, and with consequently much dead water, without producing serious strains from unequal expansion, due to the difference in the temperature of various parts, which may cause leakage."

36. *"Natural self-acting circulation is more efficient than mechanical circulation;* but the promotion of active circulation of the water by any means is of great importance, because agitation of the water assists the transmission of heat and greatly conduces to evaporative efficiency. *A steam boiler cannot be hard worked or forced with safety, unless it has provision for free and active circulation of the water."*—p. 246 of Hutton, as above cited. This reference to artificial circulation is due to the fact that some authorities, realizing the impossibility of getting sufficient water speed by natural means in any boiler design then known, took the stand that to produce it mechanical means must be adopted. See pp. 260 to 262 of Rowan, as cited in the next Section, and his conclusion that "There should evidently be a development of this system carried out, by which not only will all the water in the boiler be circulated by means of a pump, but also the water be propelled through the boiler passages, or over the heating surface at a *greater speed* than that which is due to the natural action of boiling. **** In addition to the control of speed of the movement of water over the heating surface which this method gives, it also gives control of the *direction in which the water is caused to flow."*

The reader is also referred to catalog of The Wickes Boiler Co., of 1911, pp. 33 to 35, and particularly to the statement of Mr. Geo. H. Babcock starting on fourth line from the bottom of page 35 of *Steam,* 35th Edition, published by The Babcock & Wilcox Co. Mr. Babcock was a close student of boiler action and he here uncompromisingly insists upon the necessity of rapid circulation, illustrates his remarks by reference to the ill-fated ships Montana and Dakota, and laments the vast loss of life and treasure due to lack of circulation in boilers.

We regret being unable to reproduce verbatim the forcible remarks of Mr. Babcock, as well as quotations from the Wickes catalog, as permission to quote was not granted by those who own the copyright of the books above named.

Unlimited evidence of the same kind as above cited, which there is not space to insert here, is available and this point is established beyond controversy.

37. Circulation Also Essential for Fuel Efficiency. This was not understood until recently, and it is common to find older writers who state the contrary, but later investigation has shown their error. See Kent's *Steam Boiler Economy,* 1st Ed., p. 240.

"It is clear then, that in order to have the heating surface efficient it must be kept free from soot and scale, and the bubbles of steam must be removed from the surface as fast as they form, so that the water can come directly into contact with the metal. *This last requirement emphasizes the importance of water circulation in the boiler.* The faster the circulation of water the faster are the bubbles of steam carried away

and the better is the contact between the metal and the water."—Breckenridge, Bulletin 325, p. 126.

"Free and active water circulation is the life of evaporation. The more rapid and perfect the circulation, the higher the *evaporation efficiency* of a particular heating surface."—Hutton, *Steam Boiler Construction,* p. 246. "As the efficiency of a steam boiler depends greatly upon the efficiency of its circulation, the heating surfaces should be arranged to facilitate the movement of the convection currents, and promote free circulation."—*Ibid,* p. 100.

"Since water is a much better conductor of heat than steam, it follows that the rapid removal of steam from contact with the heating surface, where it is generated, and its replacement with water will increase the transmission of heat into the boiler; that is, *the capacity, and therefore the efficiency* for a given output, will be increased."—Edge Moor Water Tube Boiler Catalog, No. 52, p. 3.

"The circulation of water is the life of all water tube boilers. Craddock's experiments show how it multiplies the effectiveness of the heating surface."—*Helios,* 4th Edition, p. 135.

38. Rowan, in *Practical Physics of the Steam Boiler,* p. 121, quotes Prof. Osborne Reynolds, a leading British authority, thus:—"The heat carried off by air or any fluid from a surface * * * is proportional to the rate at which particles or molecules pass backwards and forwards from the surface to any given depth within the fluid."

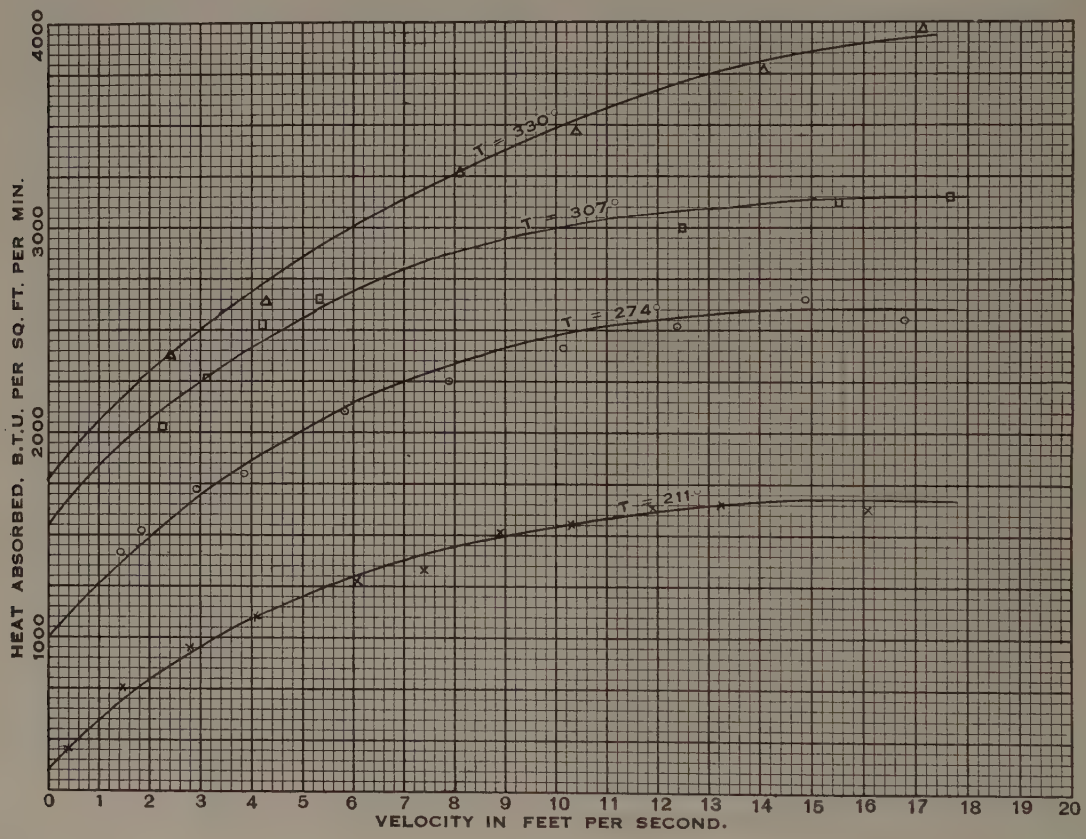


FIG. 2. CLEMENT & GARLAND'S EXPERIMENTS ON RELATION BETWEEN WATER SPEED AND HEAT ABSORPTION

He then shows that the rate of this diffusion depends on the natural internal diffusion of this fluid at rest, and on "the eddies caused by visible motion which mixes the fluid up and continually brings fresh particles into contact with the surface. The second cause, the effect of eddies, * * * is proportional both to the density of the fluid * * * *and the velocity with which it flows past the surface.*" As another illustration of the effect of velocity he says:—"The cooling effect of a wind compared with still air is so evident

that it must cast doubt over any hypothesis which does not take it into account."

39. The facts set forth above and in the following sections show the error of assuming that because several boilers may have equal heating surface they therefore have the same capacity and efficiency. See Sect. 227.

40. Experimental Proof that Circulation Increases Fuel Efficiency. It seems strange today that anyone could question this, in view of the statement of Powles quoted in Sect. 346 and the numerous experiments that have proved the necessity of rapid water circulation in condensers. To eliminate all doubt the following experimental proofs are given.

Fig. 2 is from page 13 of *A Study in Heat Transmission*, by Clement and Garland, in Bulletin 40, University of Illinois Experiment Station. The temperatures marked on the curves are those in the steam jacket around the pipes conveying the water which absorbed the heat. These curves prove conclusively that the greater the speed of the water the greater the absorption of heat. The same thing has been proved by many other investigators as shown by Fig. 3 which is from Gebhardt's *Steam Power Plant Engineering*, p. 532, and summarizes the results of 10 different sets of experiments.

On pages 125 to 129 of his book Rowan, above cited, describes and illustrates graphically Hageman's "experiments to investigate the influence of speed of water on the heat transmission," and summarizes these thus:—*"The principal result obtained previously, namely, that the transmission of heat increases with increasing speed, is further confirmed.'*

41. Breckenridge, p. 163, Bulletin 325 above cited, proves experimentally that in a water leg boiler "the circulation rapidly drops behind the amount of steam made (per cent of rated capacity developed), *especially at high rates of working.* * * * This failure of circulation to keep up proportionally with demands on it *must decrease the efficiency of the boiler* at higher rates of working, by allowing a proportionally larger percentage of the water heating surface to be covered with steam bubbles, thus virtually reducing the heating surface. That this condi-

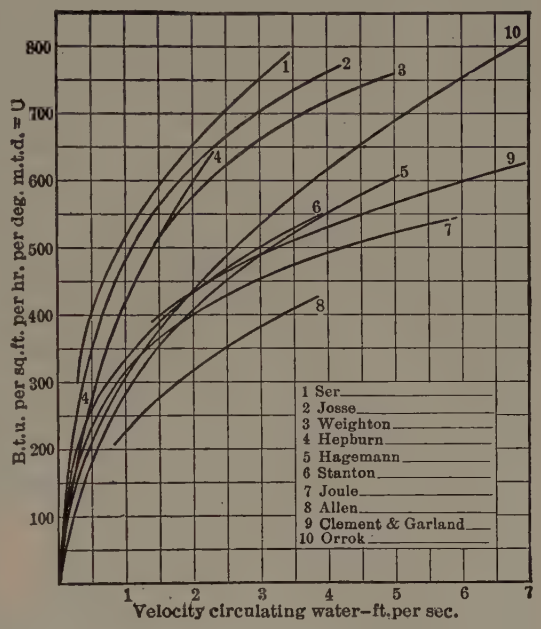


FIG. 3. RESUME OF EXPERIMENTS ON CIRCULATION

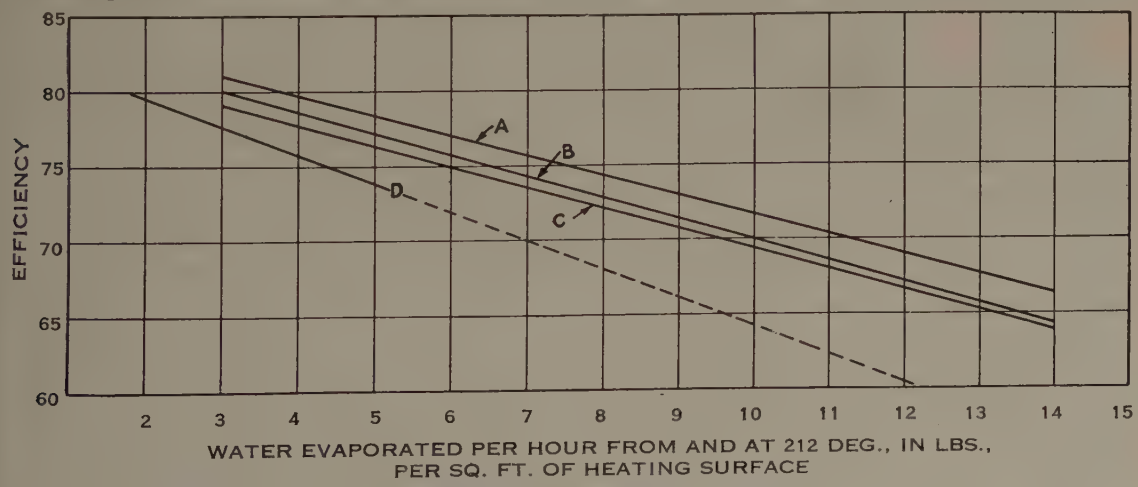


FIG. 4. SHOWING RELATION BETWEEN FUEL EFFICIENCY AND SPEED OF WATER CIRCULATION

tion does supervene is indicated on a number of charts," which are shown in the Bulletin cited.

42. That water speed increases the fuel efficiency is also shown by Figs. 4 and 5. In Fig. 4 line A represents results obtained from Stirling boilers, and lines B and C results from Babcock & Wilcox boilers of U. S. *Cincinnati* and *Wyoming*, all as given in *Tests of Large Boilers at the Detroit Edison Co.*, in A. S. M. E. Transactions, Vol. 33. Line D shows results of test on boiler in Fig. 35 for which see Sect. 75. These results are in direct order of the speed of water circulation in the boilers.

In Fig. 5, line A represents the same boiler as line A in Fig. 4, and lines B and C indicate results from a composite type, and a well known

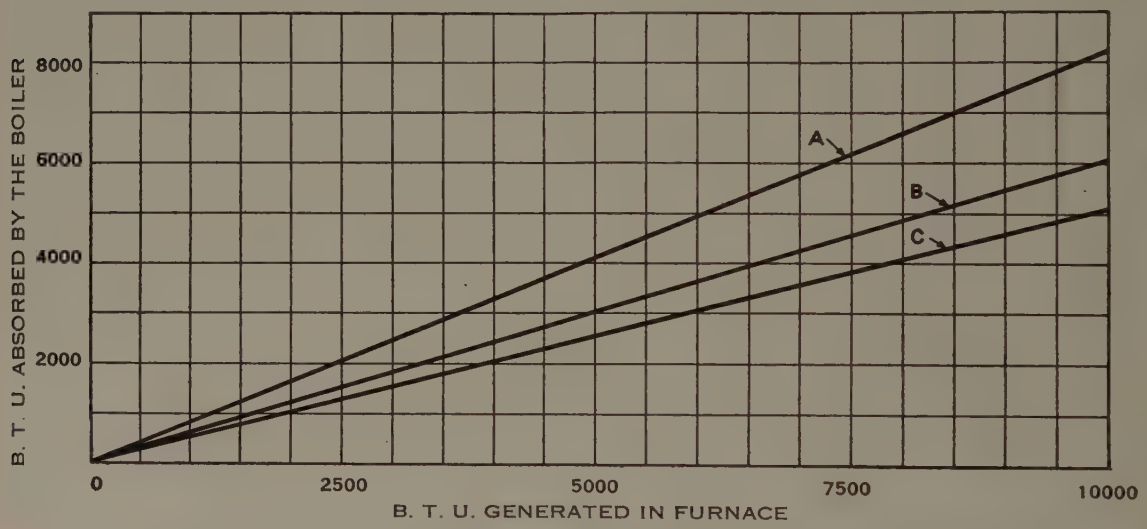


FIG. 5. SHOWING BY LUCKE S "STRAIGHT LINE LAW" HOW EFFICIENCIES VARY WITH SPEED OF WATER CIRCULATION

water leg type. These lines refer only to the heat absorbed by conduction and convection, and are plotted according to the "straight-line law" as originated by Prof. Lucke and explained in his *Engineering Thermodynamics*, p. 781. Here again the efficiencies vary in the same order as the speed of water circulation.

43. Every Burnt Tube Indicates a Loss of Fuel because the heat which should have been transmitted to the water has instead been taken up by the metal. Since overheating is prevented by rapid circulation this further proves that circulation is essential to fuel efficiency. This does not appear to have been enunciated before, though some have vaguely realized it. Thus Bancel in Par. 2 of *Circulation in Horizontal Water Tube Boilers* states:—"It is important that the tubes subjected to these (heavy) loads have ample circulation of water, and be kept clean of scale as well, *otherwise the resistance to heat transfer on the water side of the tube will increase,* causing an increase in the temperature of the metal, which if high enough, will result in rupture. *An increase in tube temperature will also decrease the heat absorbed by radiation and reduce the efficiency.*"

Kent, in *Steam Boiler Economy*, First Edition, p. 240 foresaw this fact:—"If there should be a film of steam, or a 'steam pocket,' on one side of the surface, keeping the water from wetting it, *the transmission of heat would be greatly diminished,* so that there might even be danger of the plates being overheated; but this condition is unlikely to happen in boilers of the ordinary forms." We are unable to concur in this last statement, as this condition did exist long before Mr. Kent's opinion was written, and many fatal explosions resulted therefrom. See British Admiralty Report, and report on Belleville boiler, in Bertin and Robertson's *Marine Boilers*, Bancel's rejoiner in Sect. 249 and the list of explosions also cited in that Section, all of which prove that the contingency considered remote by Mr. Kent has long been a frequent and serious fact.

44. Durston's Experiments confirm this. "When the non-conduction of heat is the result of the formation of bubbles of steam, *which are worse conductors even than grease,* the result is yet more marked. Sir John Durston measured,

by means of fusible alloys, the temperature of the tube plate of a direct-tube or Admiralty boiler, working under forced draught. The maximum temperature of the hot gases was 3,090°, and that of the water 356° Fah. The temperature of the tube plate was found to be 1,060° upon the outer surface, and 716° in the center of the thickness of metal. *It will be seen from these figures that the formation of a steam pocket may easily lead to the burning of the tube plate.*"—Bertin and Robertson, *Marine Boilers,* p. 196.

Later investigations by U. S. Bureau of Mines show that the temperatures as determined by Durston are higher than exist at the points named; the reason is that the fusible plugs absorbed heat partly from the hot gases instead of wholly from the metal sheet. This, however, does not affect the validity of the experiments as to illustrating the fact above cited.

45. A tube overheats and burns because the heat cannot pass through it and enter the water, *hence this heat is useless for generating steam, therefore is wasted, consequently the efficiency begins to drop just as soon as a tube begins to overheat.* This is one unchangeable fact of physics, and it cannot be evaded, therefore the greater the tendency of a boiler to burn its tubes, the less its fuel efficiency. The only prevention of such trouble is rapid water circulation. But the loss of fuel efficiency thus caused is trivial compared with the loss as to efficiency of Capital (Sect. 106) due to interruption of service, replacement of tubes, etc.

46. What Causes Water to Circulate in a Boiler? Since circulation is a necessity, it is essential to understand what produces it, especially as most of the published information is inaccurate. The catalog of a prominent manufacturer states "In the boiler the difference in density between the body of water in the rear header and the body of mingled steam and water in the tubes and front header causes a positive downward flow to take place in the rear header, the solid body of *COOLER WATER* continually displacing the *hotter body* in the tubes and front header." This exposition is incorrect. See Fig. 7 and Sects. 49 to 57. It applies to what happens *before the boiler is steaming,* and as stated by M. Bertin (Bertin and Robertson's *Marine Boilers,* p. 408) the velocity due to such cause would not exceed 2 inches per second. This is confirmed by the statement of Prof. Watkinson quoted in Rowan, *Modern Steam Boiler,* p. 266: —"The circulation is, then, not produced by a difference in density between (the water in the columns filling) the two vertical limbs" (of the U-tube). The words between parentheses were inserted by us to make the quotation clearer when taken apart from the context. A difference in density due to a difference in temperature will assist, but it is neither essential nor sufficient to be worth taking into account.

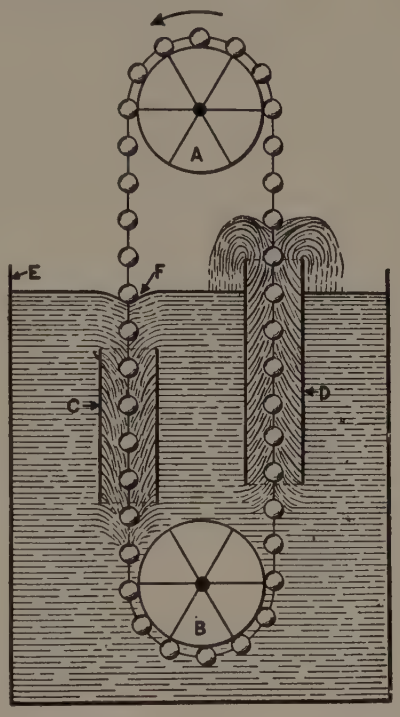


FIG. 6. SHOWING HOW STEAM BUBBLES CAUSE CIRCULATION

47. The Real Cause of Circulation *when a boiler is steaming* is thus stated by Bertin:—"The rapid circulation of boilers now under consideration is due to the action of the steam bubbles in the ascending portion of the current."

48. To make this clear refer to Fig. 6. Rig up pulleys A and B with a belt containing spheres as shown, and passing through tubes C and D which are fastened into place in the tank E. All non-metallic liquids have *ADHESIVENESS,* or the property of sticking to things, hence when the belt is travelling the water will be depressed at F., due to its surface tension, and will adhere to the spheres as soon as they are submerged, so that there will be a rapid downward water current in C and upward current and lifting of the water in D. This lifting is due solely to the fact that as the water sticks

to the spheres it is pulled along by them, hence this apparatus will elevate fluids to a considerable height, very efficiently, and is used for lifting gritty water, sewage, etc. Now, assume that instead of solid spheres, steam bubbles were attached to the belt, and that the water was of the same temperature as the steam so as to prevent condensation, then the steam bubbles would pull the water upward as before, and the faster they travel the more water they will lift.

49. It is precisely this action which causes water to circulate in a boiler, and the speed of circulation may reach 6, 8, or 10 feet or more per second, *if the steam is permitted to rise without interruption or restriction due to imperfect boiler design!* In many boilers, header types in particular, the average speed may not equal even 1 ft. per second, but such slow speed is always due to obstructions in the path of the flow. *THEREFORE, ANY CAUSE WHATSOEVER THAT RETARDS OR INTERFERES WITH FREE WATER OR STEAM TRAVEL REDUCES THE CAPACITY, EFFICIENCY, DURABILITY AND SAFETY OF A BOILER, AND ACCELERATES THE DESTRUCTION OF ITS TUBES BY OVERHEATING!* And it is precisely in this detail that nearly every previous boiler design is inherently faulty, and cannot be corrected, as will gradually appear. Read Sects. 275 and 276.

50. Glass Models to Illustrate Boiler Circulation. A correct understanding of circulation is so vital that the reader must guard against being misled by glass models. These are often used in demonstrations, but unless the experiments are conducted and interpreted by a qualified physicist and the details are arranged so as to show *what ought to be shown,* such experiments are useless, or even misleading. The reason is that in such experiments the heat can be, and usually is, applied *only at certain points* on the model, and in this way the operator can *apparently* prove anything he wishes to prove. Yet, even in such cases it is frequently found that *if the model be kept at work long enough to insure all parts being thoroughly heated, the circulation reverses itself and goes in directions contrary to those shown at the start when parts of the model were cold!* See bottom of p. 62 in Stromeyer, *Marine Boiler Management.*

In an actual boiler the entire heating surface is swept by hot gas,—a condition seldom or never duplicated in such models. But a still greater difference between the conditions existing in an actual boiler and in a model is due to three things:—(a) The head, or pressure, of the water in the boiler is far greater, and this affects both the boiling points, (Sect. 53) and the size of the bubbles formed, (Sect. 57[d]); (b) The small bore of the tube in the model and the greater size of the bubbles formed therein, for the reason above given, cause the bubbles *to fill the tube completely* like pistons, which does not happen in a properly designed boiler having good circulation; (c) Emulsification of the steam, (Sect. 51) such as occurs in a good boiler is therefore impossible, so that the model does not duplicate the action in a real boiler.

In consequence, boiler purchasers should give no consideration to indications of such models when used by salesmen to bolster their arguments. Competent authorities well understand this. "The action of boiling is resisted when made to take place in glass vessels and in those formed of materials which attract water. In such vessels ebullition is not continuous. Ebullition, therefore, is not truly represented in small glass models, although many have been used by selling agents to illustrate some so-called faulty action in other makers' boilers."—Parsons, *Steam Boilers,* p. 10.

51. Emulsification and Slip. If water had neither viscosity nor adhesiveness, a submerged bubble of steam would rise with such great velocity that its acceleration would exceed 4000 ft. per second! But the resistance due to the adhesion of the water to the steam bubble "reduces the velocity attained by the steam and at the same time imparts velocity to the water, so that the two velocities tend to approach each other, the more minutely subdivided the steam, the greater being the resistance to *free rise* through the water. In other words, the smaller the bubbles, *the less the slip of the steam* through the water. When the subdivision is very great *an emulsion is formed,* and we can assume that the steam and water flow together at the same velocity."—Bancel, *Circulation in Horizontal Water Tube Boilers,* A. S. M. E. Transactions, 1915. As also shown by M. Bertin in his *Marine Boilers,* p. 409, emulsification of steam and water is essential to good circulation. Anything which causes the steam to aggregate into large bubbles will increase the slip and reduce the speed of the water, *and this can be carried to a point where the water will circulate but little, if any at all!* "The head producing flow of water from a water leg into the

drum is created *almost entirely by the tubes,* and principally the bottom row, whereas the rising steam bubbles in the water leg *should* greatly assist the circulation in the tubes. *Under these conditions the higher the boiler the poorer may be the circulation.*"—Bancel, above cited, p. 1015. This greatly affects the action in all header types, particularly when they are many tubes high, as is becoming more frequent. See Sect. 259 and Fig. 78B.

52. Proportioning of the Water Circuit. Since the greater the amount of steam being generated, or conveyed in a tube subjected to

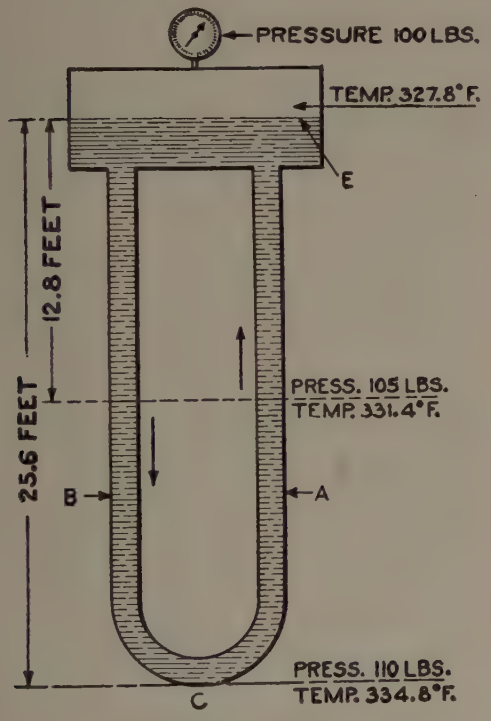


FIG. 7. ELEMENTARY FORM OF BOILER

high temperature, the faster the water must travel to protect that tube (Sects. 35 and 36) it at once becomes clear that *if in the water circuit of a boiler the speed of travel is faster in some parts than in others, the greater speed must always be over those surfaces exposed to the highest temperature or conveying the greatest quantity of steam,* if such boiler is designed for high capacity and efficiency. Yet it will be shown that nearly every design for which most extravagant claims are made grossly violates this fundamental and essential principle, hence is faulty. Therefore, regardless of what the water speed may be elsewhere in the circuit, as in Fig. 34, the capacity of every boiler is strictly limited by the water speed in the tubes over the fire. See Sects. 27 to 77, and 249 for the effect of this fact.

53. Variation of Pressure and Boiling Point With Depth. That such variation exists is seldom realized, yet it has a vital influence during the whole process of generating steam, hence must be thoroughly understood. In Fig. 7 assume a steam pressure of 100 lbs. per sq. in. absolute, and apply heat along the entire length of the U-tube, and in sufficient quantity to keep the water *everywhere up to the boiling point.* Further assume the height of vessel as marked on the figure, then this gives at the bottom of the vessel a hydrostatic pressure of 10 lbs. per sq. in., as the mean temperature of the water will be 331.4 deg., at which temperature water weighs 56.25 lbs. per cu. ft. Also assume that leg A receives more heat than leg B so that A is the up-comer and B the down-comer.

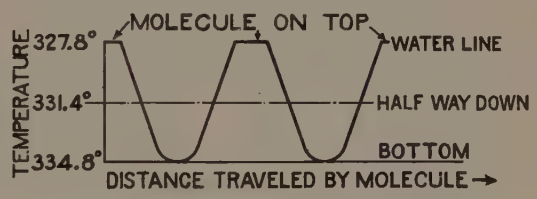


FIG. 8. SHOWING RELATION BETWEEN DEPTH AND TEMPERATURE

54. We shall now determine what temperatures will exist at various parts of the circuit.

From a steam table the steam space temperature is 327.8 deg. Fah. At the bottom the pressure per sq. in. is 10 lbs. hydrostatic and 100 lbs. vapor, total 110 lbs., hence the temperature at C is 334.8 deg., otherwise the water cannot be boiling as assumed. Likewise, the temperature half-way down is 331.4 deg., and the pressure 105 lbs. per sq. in.

55. If we could follow a molecule of water around the circuit and determine its temperature at each point and plot this the resulting curve would be like Fig. 8. Therefore, if such molecule starts at E on the water line, it will undergo all the ranges of temperature from 327.8 deg. on top to 334.8 on the bottom, and then return again to its original temperature. But it can do so only by *receiving heat* regularly on its downward trip and *yielding up heat regularly on its upward trip, and the amount it absorbs in the down-comer is precisely equal to what it*

gives up while in the up-comer, as its initial and final pressures and temperatures are identical.

56. If steam is formed at any point, its temperature is the same as that of the water at that point. But as the temperature of boiling varies with the pressure, and the pressure increases with the depth, the boiling point does also. This shows the error of the oft-quoted statement that "a constant circulation of water throughout the boiler" can or will "maintain all parts at the same temperature" as asserted in *Steam*, p. 27, Art. 5.

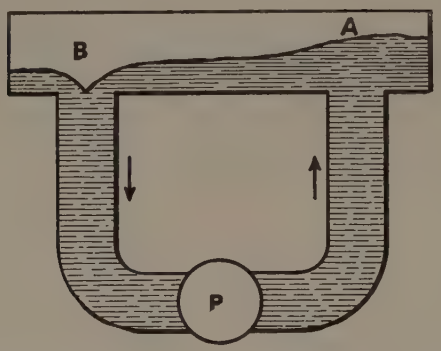


FIG. 9. U-TUBE WITH PUMP TO CIRCULATE WATER

57. Frequent reference must be made to the principles above deduced, hence they are summarized as follows:—

(a) In a boiler under steam pressure the lowest pressure is in the steam space, and the greatest pressure at the bottom of the water space, and the pressure at any level is equal to the sum of the vapor pressure plus the hydrostatic pressure at that level.

(b) In a boiler generating steam and whose heating surface receives sufficient heat to keep *all* of the contained water up to the boiling point, *the coolest part of the interior is the steam space,* the hottest part is at the bottom of the boiler, and any isothermal plane must be horizontal, and the temperature of such plane will be that corresponding to the boiling point of the water under the pressure existing in that plane.

(c) Under the same conditions as just stated, the water in its circuit through the boiler will start from the water line at the steam temperature corresponding to the gauge pressure, then steadily receive heat and increase in temperature during its path through the down-comer, and exactly reverse this action in the up-comer, so that the heat received in the down-flow will exactly equal the heat given up during the up-flow.

(d) A bubble of steam formed near the bottom of the up-comer will rise through water which is constantly decreasing in pressure as it approaches the steam space, hence is decreasing in temperature also, therefore the steam bubble must likewise decrease in both temperature and pressure, and give up some of its heat. The heat so liberated is available as additional latent heat to generate that much more steam. Since the steam bubble in its rise passes into a region of reduced pressure (as well as temperature) the specific volume of the steam increases, hence the size (volume) of the bubble increases in proportion.

58. Causes of Unequal and Fluctuating Water Levels. This is a detail of utmost importance, yet little understood, hence must be made plain. Let Fig. 9 represent an ordinary U-tube with a centrifugal pump P so located that its speed can be varied at will. As the pump operates the water surface will be like A-B, and the faster the pump works, and the greater the distance between the up-comer and down-comer legs, the greater the height of A above B, therefore in any boiler in which the up-comer and down-comer are located at a distance apart, the difference between the highest and the lowest point at the water surface will be the greater in proportion as this distance is greater. Also, it will likewise increase as the quantity of water passing (boiler rating) is increased, because it is solely the difference of level between points A and B which causes the water to flow. For an illustration from an actual boiler see Fig. 100.

59. Now rig up like Fig. 10, and locate in it a tube E with swinging check valve F, then the constricted area at A will cause a fountain effect above and such an increase in the back pressure below the nipple that as the pump speed increases this pressure will open the valve F and compel part of the water to reverse its circulation! This explains the phenomenon of "back-boiling," or reversal of flow, in header types of boilers, and since before reversing, the water speed must decrease to zero this explains why the top tubes in such designs are quite inefficient and often fill with mud. See Sect. 119. To prevent spouting a horizontal baffle plate must be imposed above the up-comer nipple, as in Fig. 65 and this still farther interferes with the freedom of flow.

60. American engineers have not until recently realized the grave consequences of fluctuating water levels, but French and German engineers have. M. Bertin built the model shown in Fig. 11, and by means of indicator tubes as shown he proved that the water line when the boiler was steaming was as represented by the dotted line.

"The rush of all the steam from the generating tubes into the front water space produces a tumultuous movement of the water in this

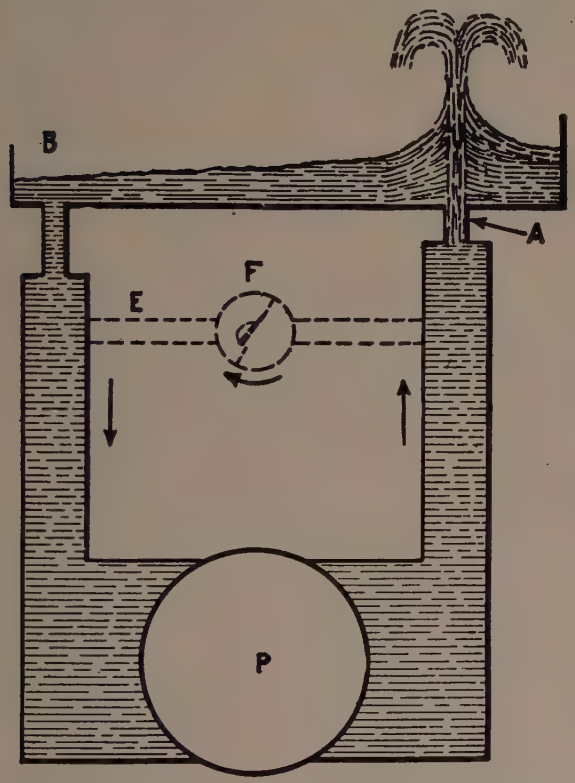


FIG. 10. SHOWING CAUSE OF SPOUTING THROUGH NIPPLES IN UP-COMERS

space and a big wave or surging in the top drum, whilst the water in the back space remains tranquil. This gives rise to a distortion of the water line, which varies with the rate of working, and is of great importance. * * * It may thus occur that in some of the rows of tubes there is *practically no circulation at all*, and in this condition *stagnation* 'pockets' of steam may be formed. Hence it is by no means impossible that certain tubes should be exposed to the risk of burning, although there may have been no shortness of water."—Bertin and Robertson's *Marine Boilers*, p. 354.

61. Notice in Fig. 11 that at the start the water *just covered the top of the tube in front*, but that when steaming was in progress, and the water in front was so high that an operator would certainly try to reduce it, even without

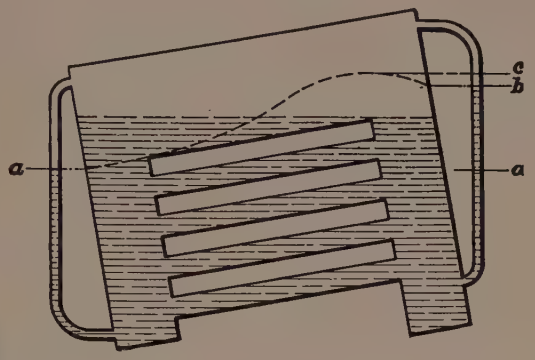


FIG. 11. BERTIN'S MODEL SHOWING DISTORTION OF WATER LINE

such reduction *the tube at the rear became uncovered, hence liable to overheat!* Right here lies the unsuspected cause of many "mysterious" explosions! But that American engineers are now realizing the dangerous consequences of such

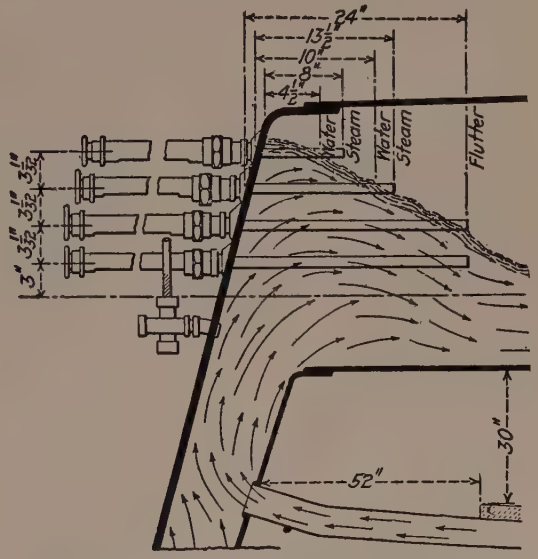


FIG. 12. SHOWING DISTORTION OF WATER LINE IN MIKADO LOCOMOTIVE

action is shown in a most interesting article, *Correct Application of Water Level Indicators in Locomotive Boilers*, in *The Boiler Maker*, Sept. and Oct., 1920, from which Fig. 12 was taken. In this, exploring tubes were used to locate steam and water, and from the figure

it is clear that while the gauge cocks may indicate ample water, the crown sheet slightly behind these cocks may be covered by but little water or none at all!

Besides the multitude of other troubles caused by fluctuating water level it also causes a loss of fuel economy, as shown in Sect. 511.

It also introduces a serious source of inaccuracy in fuel tests as shown in Sects. 112, 299 and 366.

We shall next point out one serious result of unequal water levels, and others are shown in Sect. 229, and Figs. 64, 100, 105, 141, 143 etc., and the text relating to them.

62. Menace of Incorrect Water Column Connections. That such menace exists is realized by but few boiler builders and still fewer boiler purchasers, yet its existence is easily shown. It may be due to two things: (a) Widely fluctuating water line as above shown, so that even if the indication of the water glass is correct it does not give warning when the boiler sheets are uncovered in some place remote from that where the gauge connection is made; (b) Incorrect location of the water connection of the gauge.

Fig. 13 shows a water leg with an outside pipe connection, the bottom of which enters the leg 20 ft. below the water line. This duplicates the construction in Fig. 66 except that here the pipe connection is assumed to be longer than shown in that figure. Assume that the boiler, of which this leg forms part, is operating at 180 lbs. gauge, so that the steam temperature is 380 deg., and that the boiler water is also of 380 deg. temperature, though as shown in Sect. 53 the water temperature increases with depth, but this will merely intensify the danger below shown to exist. Further assume that the fire room temperature is 80 deg., and that this will also be the temperature of the water in the outside pipe connection.

A cubic foot of water at 80 deg., weighs 62.23 lbs. and at 380 deg. it weighs 54.36 lbs. The pressure due to the hot water at the bottom connection of the stand pipe will therefore be $20 \times 54.36 = 1{,}087.2$ lbs. per sq. ft. The height of a column of water at 80 deg. to balance this will be $1{,}087.2 \div 62.23 = 17.47$ ft. But $20 - 17.47 = 2.53$, hence the water level at the top of the stand pipe will be 2.53 ft. or 30.36 inches *lower than that in the boiler!* Put a gauge glass into this pipe, and its indications will be in error by just that amount!

In any practical case the water in the standpipe would be of a temperature slightly higher than that of the room because of condensation in the top connection to the column and heat radiated from the boiler front, but if any reasonable increase of temperature be assumed, and the computation made on that basis, the error of indication of the column will still be found too great to be tolerated.

This explains many otherwise "mysterious" explosions, and wrecking of engines by slugs of water carried into the mains, because if the operator goes by the gauge glass the water will be carried too high in the boiler.

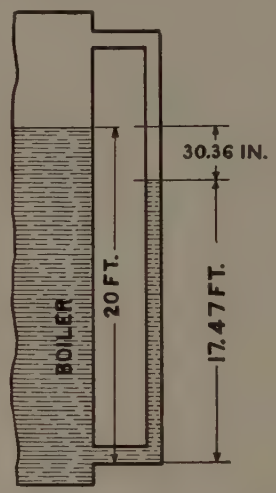


FIG. 13. SHOWING FAULTY WATER COLUMN CONNECTION

Therefore, to insure a correct indication *the bottom connection to the gauge glass must be located as nearly as possible just under the lowest permissible water line in the boiler.*

63. But this precaution alone is far from sufficient. Another of equal importance is to make the bottom connection at a point where the water is *not in rapid motion,* otherwise the gauge glass will also give a false indication. For instance, if fast moving water impinges directly upon the opening for the bottom connection, the kinetic energy of the stream will make the gauge glass read too high by an amount equal to the head necessary to produce the water velocity, precisely as in case of a Pitot tube used to measure the velocity of water and gases. In such cases, not only will be indicated level be wrong, but it will seesaw up and down with every change in the rate at which the boiler is operating. See Sects. 298 to 301

352 to 354, 366, etc. But if the water is flowing *away from* the opening, this may create a suction effect which will make the glass indicate a level too low, which is equally dangerous.

64. The next requirement is that the column must be connected to such point as will show what the operator should know; namely, where the true water level is. This requirement is seldom met. Note Fig. 100 from *Power*, Sept. 6, 1921. If another column were connected to the rear of the drum its indications would be far different from those in the column located in front as shown. And the level in both such columns would seesaw as the rate of operating changes. The natural question then is which column should the operator depend upon?

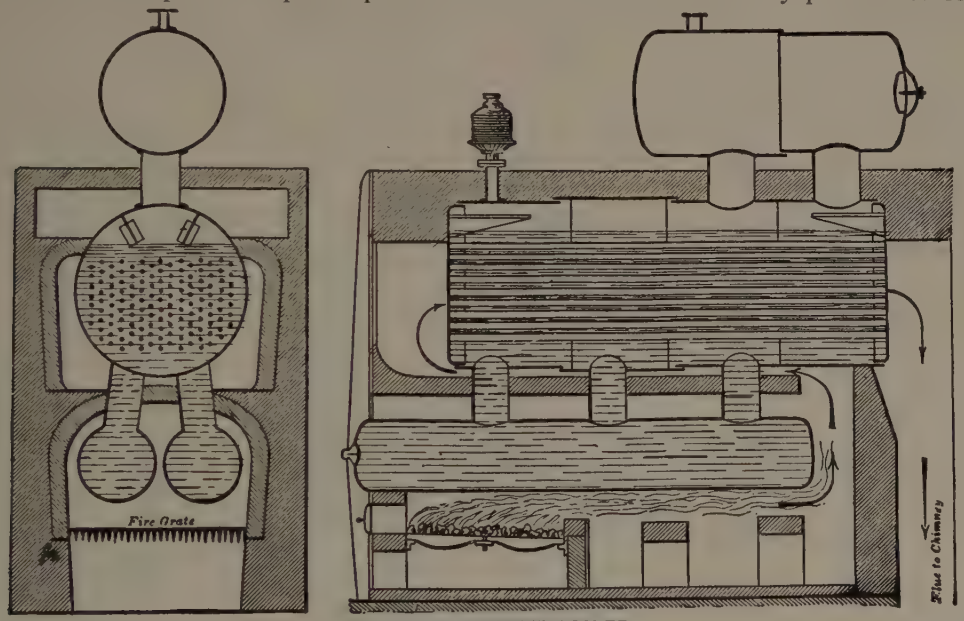


FIG. 14. ELEPHANT BOILER

65. Refer to Sects. 298 to 301 and Figs. 102 to 105 and 141 to 143, and note that by attaching water columns to the various drums a wide choice of water levels is available, and that these afford further variety by fluctuating with each change of load. Which of these should be considered as giving the true level to guide the operator?

The above explanation clearly proves that insufficient study has been given to proper water column location, and that at times the indications of the column are inaccurate, misleading or even dangerous, and that extremely few columns show the *true average water level!*

Finally, the water connection to the column should be as *short and direct as possible.* The longer this connection, the greater the temperature difference between it and the boiler water, hence the greater the error of the indication as shown above. And also, the greater the liability of stoppage of the pipe from mud, and the difficulty of cleaning it. Figs. 102, 142 and 143 show designs which are lacking in this respect.

Reference to Fig. 163 and Sects. 417 and 504 shows that in the Kidwell boiler the column connections are such that the glass shows the *true water level,* which does not jump rapidly with each change of load.

67. Origin of Horizontal Types of Water Tube Boilers. No student can have failed to note that up to 30 years ago practically all water tube boilers of any prominence consisted of some scheme of connecting inclined straight tubes to some form of header terminating in a drum above. While that general type still survives it is an evolution of an originally wrong idea, and its deficiencies can not be overcome. In consequence, most such designs prominent several decades ago are now extinct, and the others will in time surely disappear as soon as the technical principles involved are understood, and boilers are bought for what they *will do to-day*, instead of what they did long ago when the requirements were far less exacting. See Sects. 274 to 278.

68. Water Tubes have been used from remote antiquity. Some beautiful specimens for heating hot water have been recovered from the

ruins of Pompeii: see Powles' *Steam Boilers,* pp. 3 to 6, and *Power,* March 29, 1921, p. 509. But the germ from which modern header designs evolved seems first to have appeared in the "elephant" boiler, Fig. 14, which originated in Europe over a century ago. Like most of its successors, it lacked definite circulation, hence steam accumulated at the top of the large tubes over the fire, as shown in Fig. 15, hence these often overheated, bagged and burst just as now occurs in modern header types of boilers whose

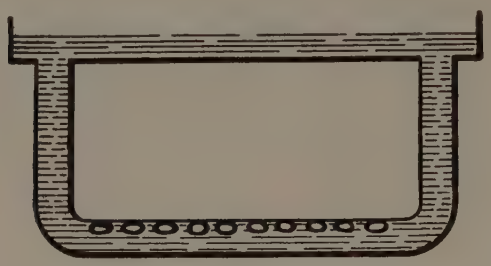


FIG. 15. SHOWING ADHESION OF STEAM TO TOP OF HORIZONTAL TUBE

circulation is insufficient to sweep out the steam as fast as formed. See Sect. 249. The unequal expansion of the bottom tubes and upper drum caused leaks in the necks connecting the two, and accumulations of mud would form on the bottom of the tubes below these necks and also cause overheating and rupture. But the general scheme marked a step in the right direction, so it later evolved into a "double-decker" as in Fig. 16. Still later a "triple-decker" appeared, like Fig. 17.

travel more rapidly and in a definite direction, so that the next step was to place the lower cylinders on an incline. As these large cylinders were difficult to make, a plurality of smaller tubes was next substituted for them, hence arose

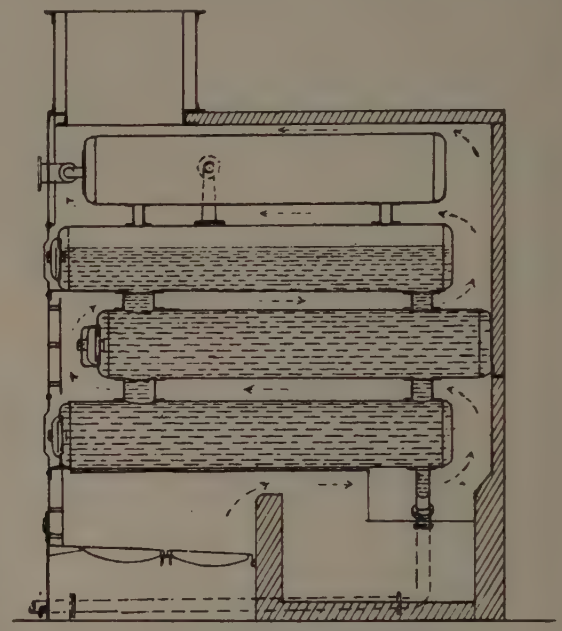


FIG. 17. TRIPLE DECKER BOILER

the difficult problem of connecting these tubes to the drum above. This gave rise to the vast number of designs for "headers," and as these were complicated in shape they were necessarily made originally of *cast iron,* thereby introduc-

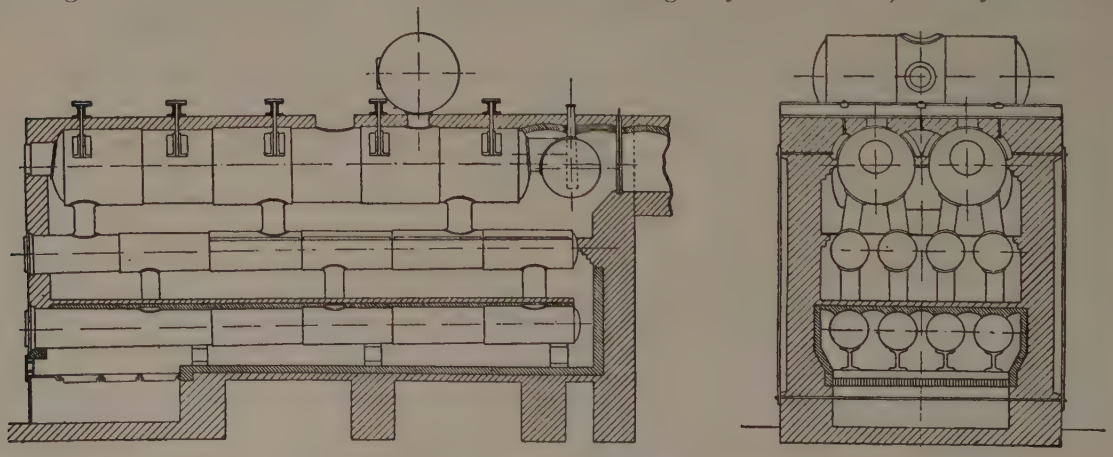


FIG. 16. DOUBLE DECKER ELEPHANT BOILER

69. Origin of Headers. To overcome the defects of the elephant boiler it was finally realized that something must be done to make the steam

ing into boiler design another most serious evil which even yet persists, in spite of many fatal accidents which in other countries has caused

this unsuitable material to be prohibited, and as in the future will be done in the United States when the public realizes the true facts. See *Boiler Explosions* in *Power*, Nov. 7, 1916, page 653.

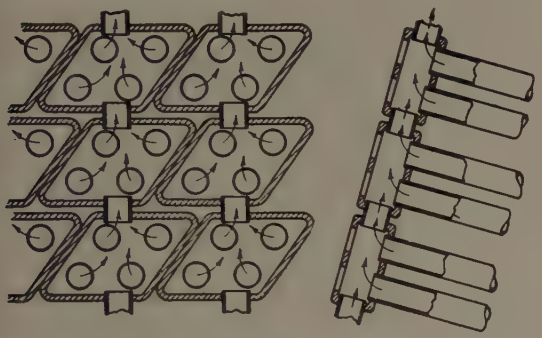


FIG. 18. CONSTRICTED HEADER

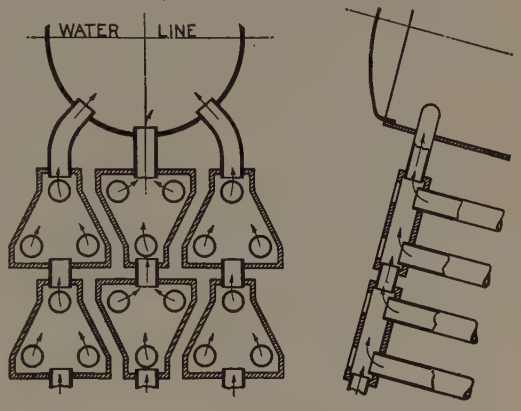


FIG. 19. CONSTRICTED HEADER

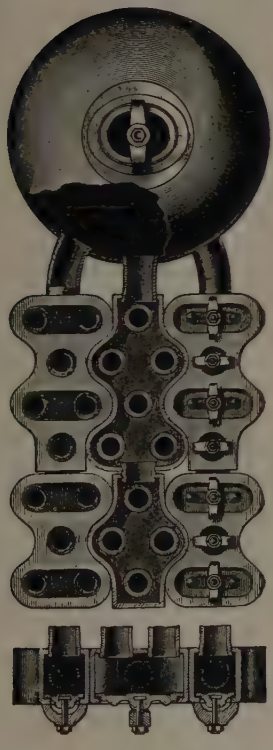


FIG. 20.
HEADER OF 30 YEARS AGO

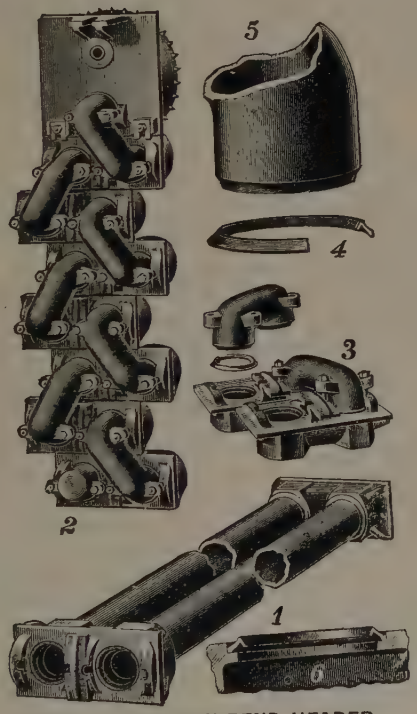


FIG. 21. RETURN-BEND HEADER

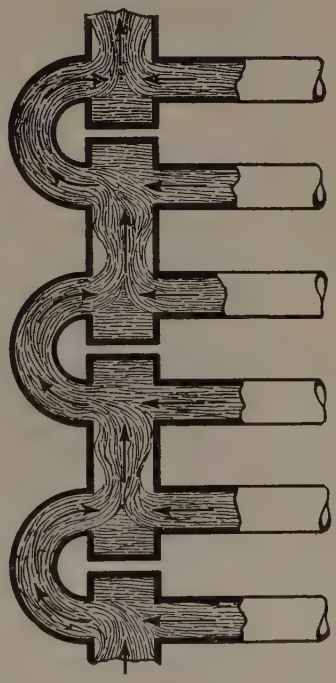


FIG. 22. SHOWING WATER PATH IN FIG. 21

70. Figs. 18 to 30 show a few such headers of a vast multitude. They all restrict the circulation to such extent that most of them have now disappeared, and the others will certainly follow them in due time. See Sects. 275 to 278.

71. In Germany a different solution of the problem was worked out by employing, instead of a multitude of small parts, a narrow box-shaped structure which could be made of wrought metal, and this gave rise to the large number of *water leg* types now in use, one of which is shown in Figs. 66 and 67. Unquestionably this is as to engineering principles far better than the other forms of headers, since it obviates the use of cast iron and reduces the throttling of the circulation somewhat, but that it still falls far short of the essential requirement as stated in Sect. 52 will now be proved by application of the principles above enunciated.

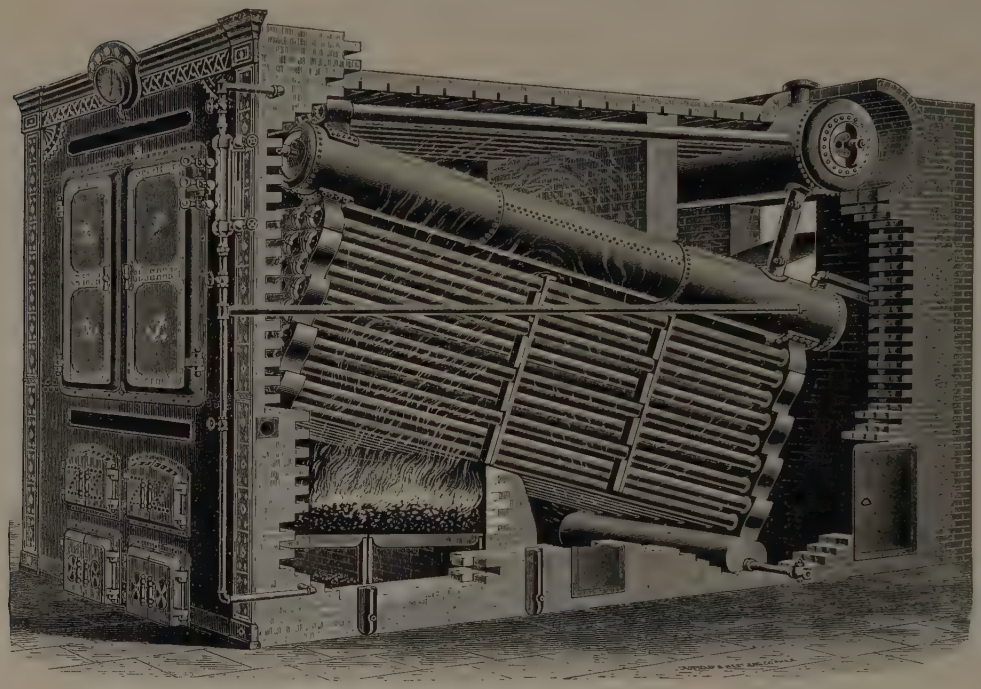


FIG. 23. THE ZELL BOILER—SIDE ELEVATION

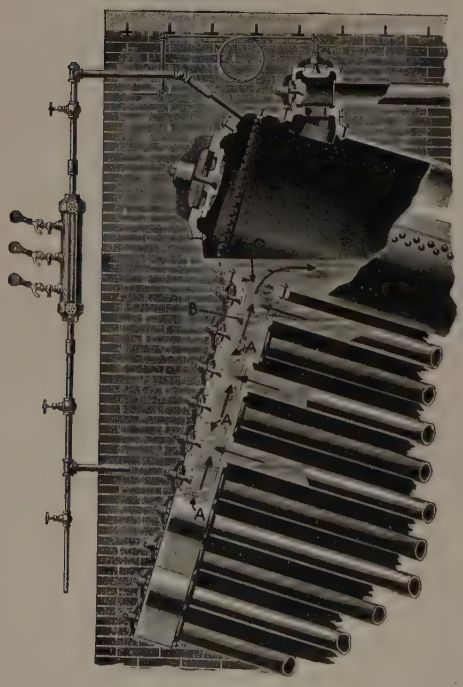


FIG. 24. SECTION THROUGH HEADERS

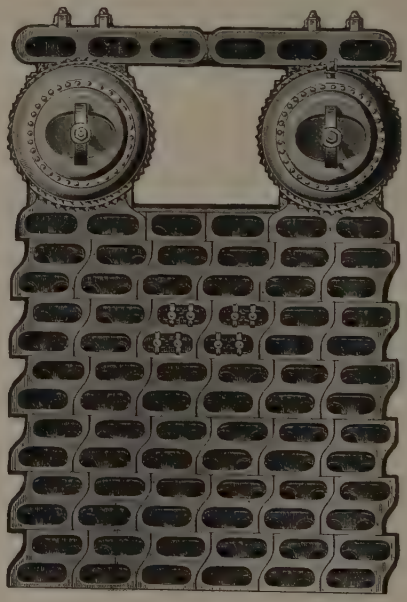


FIG. 25. FRONT VIEW OF FIG. 23

☞ The particular feature of this design which justifies its reproduction here is the use of the overhead steam drying tubes, for which see Sect. 513.

FIG. 26.
SINUOUS CAST HEADER

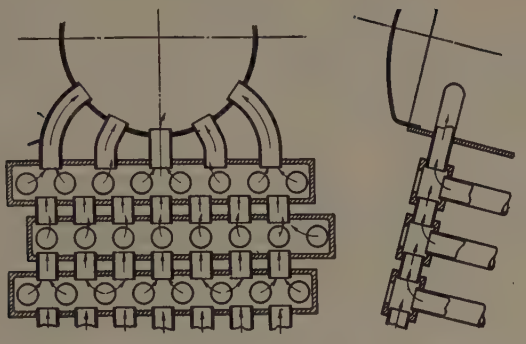


FIG. 28. A HEADER SCHEME WHICH DIED QUICKLY

FIG. 29. HEADER, CAP, BOLTS AND NUTS USED IN FIG. 30

FIG. 27.
RECENT MALLEABLE HEADER

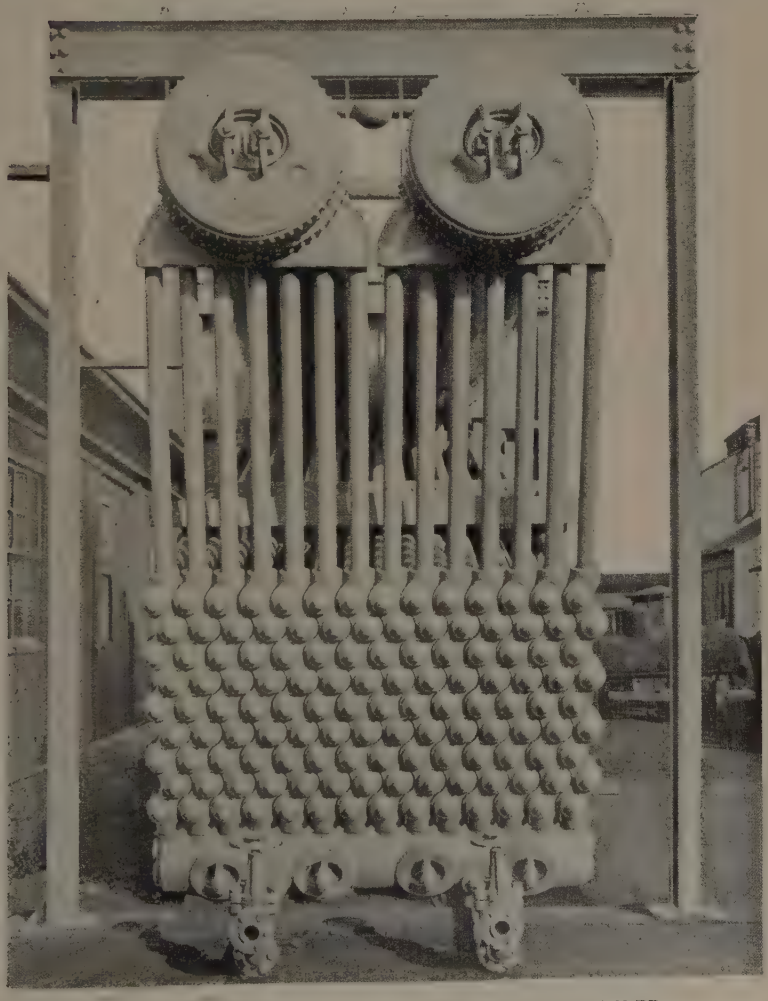


FIG. 30. REAR VIEW OF A SINUOUS HEADER BOILER

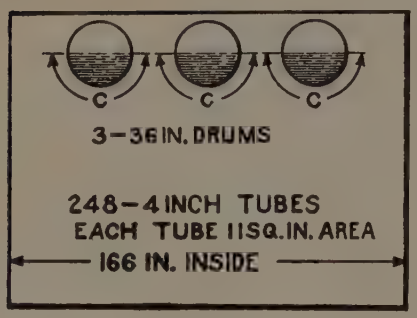
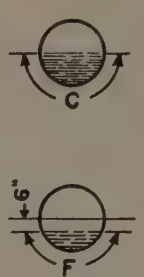


FIG. 31



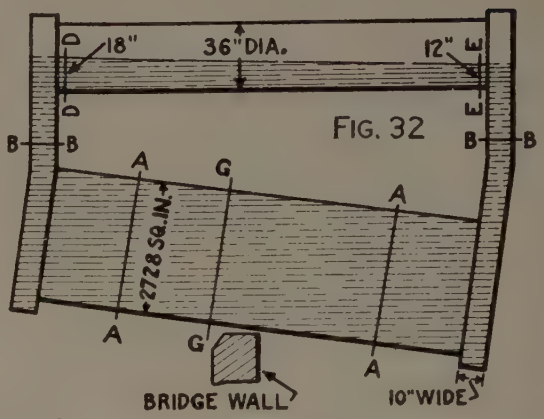
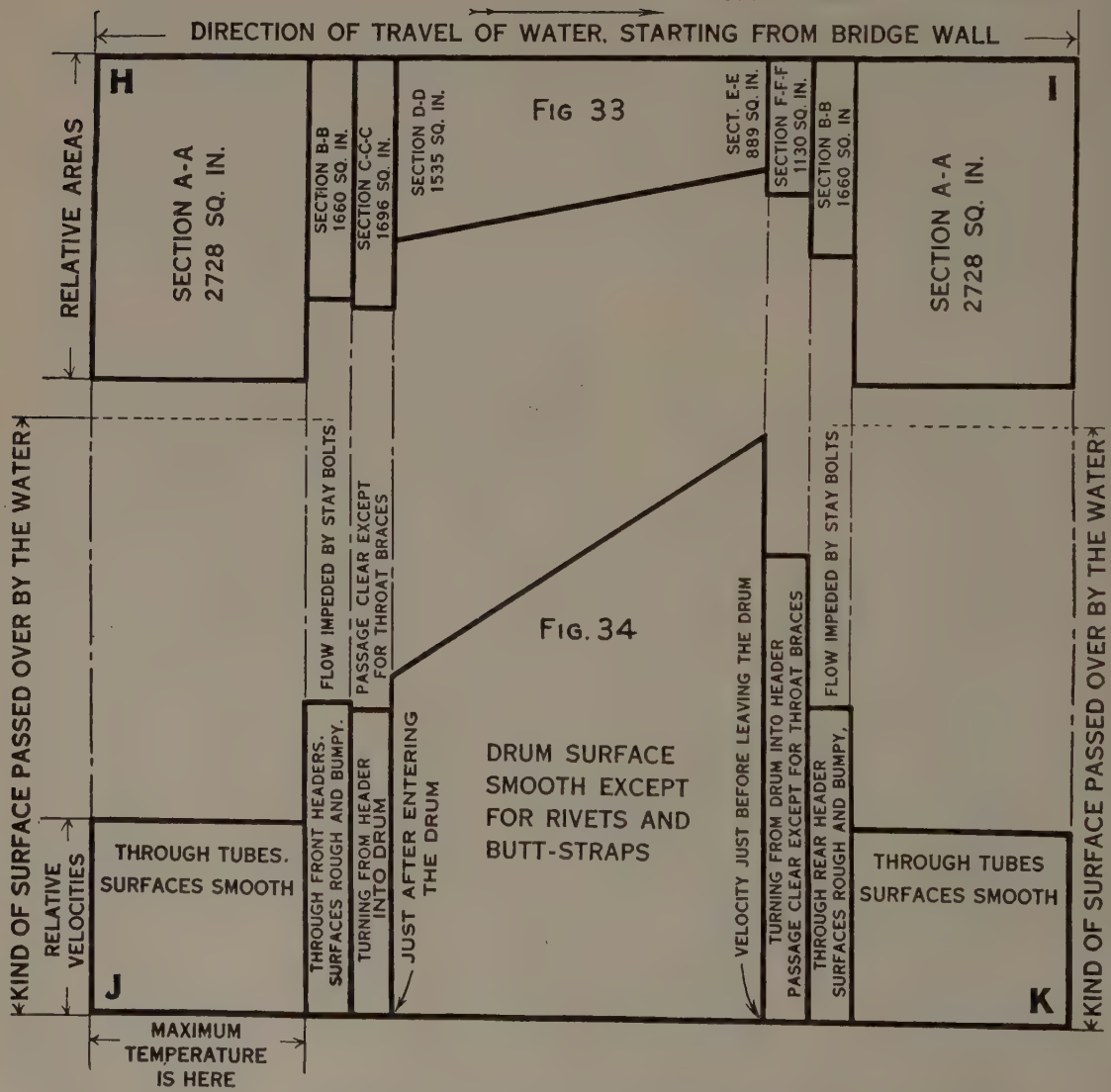


FIG. 32



AREA-VELOCITY DIAGRAM OF AN IDEAL WATER LEG BOILER WITH MINIMUM THROTTLING OF THE WATER CIRCUIT

72. Assume an ideal boiler like Figs. 31 and 32, with a box header 10 inches wide in the clear. *We have purposely made this boiler wide and shallow, and with a degree of constriction in the water circuit far less than probably 99% of header types of boilers in use,* and have intentionally given the design every advantage, so that if we prove that this arrangement falls far short of the necessary qualifications, then naturally others less perfectly proportioned will upon analysis show up even worse.

When the boiler is operating the water in the drum cannot be level, as proved in Sects. 58 to 61, and simply to keep the resulting diagram of a size to fit the page of this book we will assume a difference of only 6 inches between the front and the rear, though if operated at the low rating of 110 to 120% the difference will be 9 inches or more, as observed in plants so operating. Also note Figs. 11 and 12.

73. Compute the net areas of the water circuit on lines A-A, B-B, etc., and lay these out as ordinates extending downward from line H-I in Fig. 33, and connect their ends, and the resulting figure therefore shows the area of the water circuit at every point. But, as the same quantity flows at every part of the circuit the velocity must be inversely proportional to the area, or Q=AV, in which Q=quantity of water passing, A=area of the circuit at any point, and V=velocity of the water at the same point. The diagram in Fig. 34 is so constructed that any ordinate in it multiplied by the corresponding ordinate in Fig. 33 will give the same result. Consequently, Fig. 34 illustrates graphically the relative water velocity in the circuit, from which the following is evident. At the trivial difference in water line assumed, the average speed of water at E-E *where the gas is coolest, is over three times the average at A-A where the gas is hottest,* which is precisely the reverse of what it should be, as proved in Sect. 52. Now assume that the rating were increased to about 120%, which is very moderate indeed. The difference in water level would then increase to about 9 in., the area at E-E would then reduce to 597 sq. in., and the water speed there would then be almost 4.57 times the average at A-A where it *should* be the greatest. As the water in the gauge glass is kept at the same line by the operator without respect to the rating being developed, it is clear that at ratings exceeding 120% the ratio of water speed will be still greater, and this must be the condition in any boiler which *operates at such ratings as are now necessary to secure adequate returns on the investment.* The ratings at which this or any other boiler can be safely operated are limited strictly to the ability of the water speed at A to keep the tube surfaces swept clear of steam bubbles, hence *there is where the maximum water speed is needed, and where with any such header arrangement it cannot possibly be gotten,* which was to be proved.

74. Unfortunately, the above proved deficiency is not the only one. When the header was made very wide so as to reduce the throttling in the water circuit it introduced another disturbing factor which partially or wholly offsets the increase in area. This is the tendency of the steam to depart from the emulsified state as soon as it emerges from the tube into the header, as shown in Fig. 78B and Sect. 259, and Bancel's statement at the end of Sect. 51.

75. Figs. 33 and 34 we call a "Flow, or Area-Velocity Diagram," and if a similar figure be constructed for any header type of boiler on the market the results will invariably show up not only worse, *but much worse* than the above, especially if the difference in water level existing at any high rating be used when plotting the figure. Ratios of 10, 16, 24, or even higher, between the water speed at the coolest part of the gas circuit, and the point directly over the furnace will be found! For example, note Figs. 35 and 36, in which this ratio is 24. Read *Tests of a 1000 HP. 24-Tubes High Boiler,* by B. N. Bump, p. 687, A. S. M. E. Transactions, 1912, obtainable separately in their publication No. 1362. Note in the Summary of Results, p. 693 that "The best combined efficiencies are obtained with 56% to 66% of the boiler rating," thus confirming the statements in Sects. 37 to 45 that circulation is necessary for fuel efficiency, as well as for working at high ratings. Line D in Fig. 4 shows the performance of this particular boiler. Further note in Fig. 35 that this boiler was covered with insulating material to reduce heat loss by radiation to a degree very seldom found even in good plants. In a present day power plant any boiler which cannot safely operate up to at least double rating and without a large drop in fuel efficiency, is not worth consideration. The boiler above referred to was not tested above 128% of rating, and in view of its constricted water circuit a high rating would certainly cause steam locking of the tubes, resulting in overheating, distortion, and failure.

FIG. 35
HEADER AND NIPPLE DESIGN WITH GREATLY CONSTRICTED CIRCULATION

FIG. 36

Thus, the constricted area at B, Fig. 37, would either cause the steam to back up in header A and upper tubes C, or lock in the tubes over the fire so they would attain the condition shown in Fig. 1, with the inevitable result shown in Fig. 45. Everyone who has tried to operate header designs at fairly high overloads for *sustained runs* will recognize this condition at a glance. See Sect. 222 for a further exposition of the deficiencies of this design.

76. It must be particularly noticed that the area-velocity diagram above described is based upon what would result if *water alone were flowing through the circuit*. Such can never be the case when a boiler is steaming, hence we must consider what additional effect the steam will produce. At 150 lbs. gauge pressure a cubic foot of water generates 151 cu. ft. of steam, hence the volume of the mixture of water and

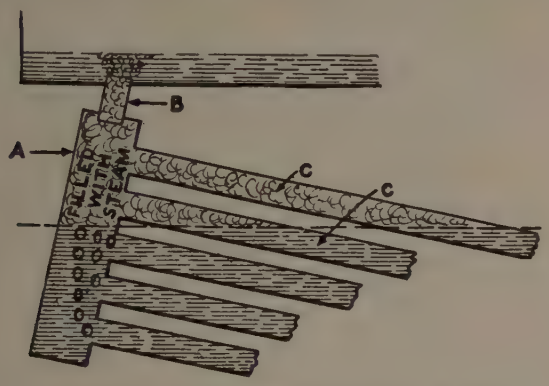


FIG. 37. STEAM LOCKING CAUSED BY NIPPLES

steam flowing through the up-comer is considerably larger than the water alone when flowing in the down-comer. Therefore it is particularly necessary that the up-comer area be not sensibly reduced, but in all header types it is considerably reduced, and extremely so in all designs using nipples as exits from headers. In consequence, if any particular case be assumed and the resulting velocity be worked out after taking the steam volume into account, the velocity diagram will show up just that much worse. It is this fact which underlies the deficiencies pointed out in Sect. 249 and following.

77. In consequence of this inevitable throttling of circulation in header designs of the various sorts the ratio of tubes lost as compared with a boiler of fairly free circulation is extremely high;—actual records have shown this to be over 60 to 1. See Sect. 147. A potent reason for this is that even at fairly high ratings it is frequently impossible to get water into the bottom tubes because of steam locking. See Figs. 80 to 86 and descriptions, and Sects. 145 and 265 which prove this.

78. Water Endurance Surface. What is even more important than large steam and water space is large water endurance surface. This term, originally introduced by Admiral Melville, is not in common use as it should be and needs explanation. Let Figs. 38 and 39 represent two simple boilers of exactly the same heating surface and water volume, the larger end of the cones being 10 feet, and the outlet 12 inches, in diameter. The water surface in Fig. 39 will then evidently be 100 times that in Fig. 38, hence at an equal rate of evaporation the water level in Fig. 38 will sink 100 times as fast as in Fig. 39, and its water endurance will therefore be only one one-hundredth that of Fig. 39. Hence we may define water endurance surface as the

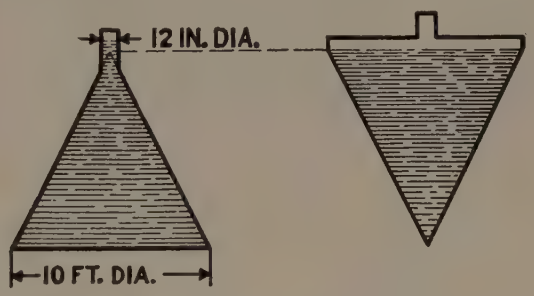


FIG. 38 FIG. 39
ILLUSTRATING WATER ENDURANCE SURFACE

net area of the actual contact surface between the water and the steam space in the boiler, and it serves as the measure of the ability of a boiler to deliver steam without dropping its water level if boiler feeding is stopped. This is a point of supreme importance in boilers, but usually overlooked until *after the boiler is in use*, at which time the water tender finds that troubles begin. Boilers containing but one drum on top, especially if of the cross drum type now being urged vigorously by manufacturers *simply because they are cheap to build*, are particularly lacking in water endurance, hence they prime, and the water level sinks rapidly—far from a desirable combination. "A rapidly lowering water level is apt to expose dry sheets or tubes to the action of hot gases, and thus be a source of danger. A rapidly rising level may, before it is seen by the firemen, cause water to be carried over to the steam pipe, and endanger the engine."—Kent, *Steam Boiler Economy*, p. 299. A perfect illus-

tration of this is given in "Cause of the *San Diego* Explosion," details of which are given in Sect. 235(b) and explain why five boilers of the general type of Fig. 68 overheated and caused an explosion aboard a cruiser. Fig. 143 shows a design equally dangerous from this cause.

79. Apparent and Real Water Surface. This is an extremely important detail almost invariably overlooked. The water surface in a boiler when *not steaming* may be, and usually is, a very different thing from what it is when in service, especially at high ratings. As proved in Sects. 58, 60 and 61, the water line in longitudinal drums cannot remain level when steaming is in progress, hence if the water is kept at the center of the drum at its front end, the rear end must be considerably lower, hence the area of the water surface becomes less than when the boiler is idle. Refer to Fig. 105 and note that the rear drum *usually contains no water,* hence the real water surface in this design may be less than one-half of the apparent surface as shown in Fig. 102 and the *effective* water endurance surface not over 40% of the apparent surface. In some designs which prime badly the water line may have to be carried so low that there is either very little water (see *San Diego* explosion above quoted), or no water whatever in the drum, so the only effective water surface is that in the tubes below the drum. Figs. 141 and 142 show designs in which this may happen, and when it does the tubes entering at the side of the drum eject the effluent in streams clear across the drum, thus causing severe priming and defeating the very purpose for which the water was lowered. This effect is more common than realized, and every design should be carefully scrutinized as to this detail. Note Figs. 10 and 76.

80. Disengaging, or Liberating Surface. These terms are widely used, often incorrectly, as careless or insufficiently informed writers use them to designate the *entire water surface,* real or apparent, not realizing that there is any difference between these two. To make their error clear bend a pipe like A, Fig. 40, insert it into water and blow into it. The air bubbles will rise to the surface at B, *directly above the orifice in A, and nowhere else!* You may blow forever, but you will never be able to scatter the air through the water so that it emerges from the whole water surface like a fog.

81. It is precisely thus in a steam boiler. The steam bubbles not only rise directly from the up-comer exit to the water surface, but are ejected rapidly by the tendency of the effluent to spout upward. Therefore, *no part of the water surface other than that directly over the up-comer takes any part in the action,* hence no other is either disengaging or liberating surface. The only time when all or part of the main surface acts as liberating surface is when the *pressure in the drum is falling,* so that the water gives up its surplus heat as described in Sect. 84. But as the water in the drum is of shallow depth the steam bubbles so formed will not emerge violently, hence they disturb the water surface but little, and the amount of steam so liberated is insignificant compared with the total. If the pressure is steady, or is rising, the

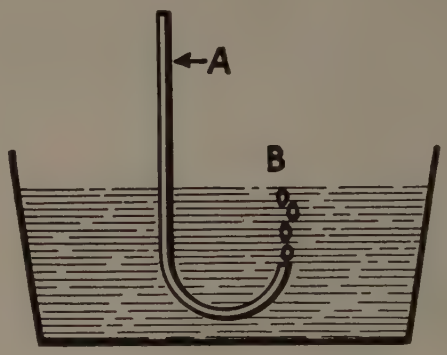


FIG. 40. SHOWING REAL DISENGAGING SURFACE

main water surface liberated no steam. Consequently, the only place where *violent disengagement* occurs is just above the up-comer, hence the up-comer cross-section is the only disengaging area we need consider. *And in header types it is invariably too small!*

82. In order to divert the reader's attention away from this fundamental fact, literature of some boiler builders will energetically urge the necessity of large liberating surface, and then adroitly convey the impression that the *entire water surface is all active liberating surface,* hence our reason for explaining why it is not. Yet these same builders, when pleading for some design deficient in water endurance surface promptly and cheerfully reverse themselves and claim that *such surface is wholly unnecessary.* Examples:—Refer to *Steam,* 35th Edition, p. 71. The second section from the top of the page urges that certain steam and water spaces, etc., have been proved necessary. In the last section on that page this writer discusses another

design lacking such steam and water spaces, so he immediately reverses himself and argues that such spaces are *entirely unnecessary!* In fact, he gravely claims that when operating at high capacity the boiler last under discussion needs no other liberating surface beyond what it gets from a row of over-comer tubes only 50-inches long! A statement of about equal import is contained in *Marine Boiler Logic,* p. 60, paragraph 2.

Draw your own conclusions!

38. Priming. Few clearly understand why many boilers prime excessively, hence the following explanation. By priming we mean the transport, by steam, of moisture which by violent spraying or agitation of the water surface has become mixed in small particles with the steam and so emulsified with it that the steam and moisture travel together. It must be clearly

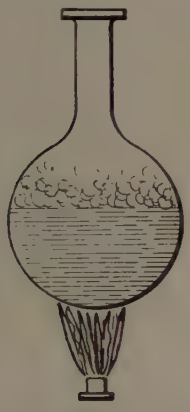


FIG. 41

FIG. 42

SHOWING BOILING CAUSED BY REDUCTION OF PRESSURE

distinguished from *foaming* which is caused by the presence in feed water of anything which causes an increase in the surface tension of the water, such as dirt, oil, sewage, syrup, or other organic matter, or it may be caused by salts which make the water "lively" like soda water.* Priming, however, results from the *design of the boiler and may occur even with pure water.* "Some boilers are so badly made (designed) that they will 'prime' with the slightest excuse. Some boilers are so well built that they will stand up and give service with almost any kind of water." —Page 42, Bulletin 1752 cited in footnote. "Water does not boil from the surface, but bubbles of steam form *throughout the mass* and rise to the surface. This action is very violent in steam boilers, and bubbles of steam rise so rapidly as often to carry considerable water in mechanical suspension into the steam. This action is called 'priming,' and it occurs most frequently in *poorly designed* boilers and in those that are forced beyond their capacity."—Parsons, *Steam Boilers,* p. 10.

84. Boil water in a flask, Fig. 41, expel all air, cork the flask, invert it as in Fig. 42, and note that boiling stops immediately. Place a

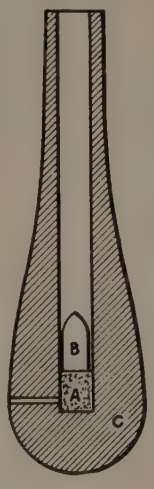


FIG. 43

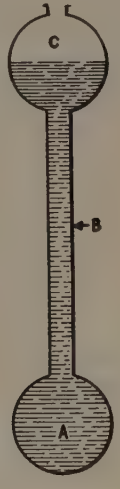


FIG. 44

ILLUSTRATING CAUSE OF PRIMING

wet sponge on top of the steam space and condense some steam. Boiling begins at once. Why? Because with all vapors a definite pressure always accompanies a definite temperature; by condensing some of the steam the pressure falls, and the water below it is then of a higher temperature than that corresponding to the reduced pressure, so the excess of heat between the original and final temperature

*A discussion of the causes and remedies for foaming is given in Bulletin 1752, University of Texas, Austin, Texas:—*Boiler Waters; Their Chemical Composition, Use and Treatment.* This excellent work should be in the hands of every one in charge of a boiler plant, as it is very complete, covering not only feed and water impurities and their treatment, but cognate subjects such as embrittlement of steel by caustic soda. On the latter subject see also, (a) Bulletin 94, Engineering Experiment Station, University of Illinois, Urbana, Ill.:—*The Embrittling Action of Sodium Hydroxide of Soft Steel;* (b) *Combustion,* Oct. 1921, p. 164; (c) *A Cure for Caustic Embrittlement* by W. L. Abbott, in *Power,* April 17, 1923, p. 607, in which the author shows how to overcome the trouble by use of sulphuric acid.

Whether steam be wet because of priming or foaming, the loss thereby caused will be as shown in Sects. 89 and 90.

is at once liberated as latent heat, which forms steam, hence starts the boiling again. Thus, suppose a vessel contains steam and water of 110 lbs. absolute pressure; its temperature, from steam table, will be 334.8 deg. Fah. If the steam pressure drops suddenly to 100 lbs., the corresponding temperature will be 327.8 deg., hence each pound of the hot water will at once liberate 334.8—327.8=7 B. T. U. of latent heat which will instantly generate a corresponding quantity of steam which rises to the water surface as in the flask experiment above described.

85. Ignite the powder A in Fig. 43, and a large volume of gas is formed. This expands rapidly and ejects the shot B with great velocity, and the longer the gun the longer the gas acts on it, hence the greater its exit velocity will be. Now, assume that in a vessel like Fig. 44 we mix intimately with the water some minutely divided water proof explosive which we can ignite by an electric spark. Then, throughout the water, bubbles of gas will be produced, their rapid expansion can find relief only by hurling the water upward at great velocity, which it will therefore do so that *the water itself* becomes a projectile and will strike the top of the vessel above the space C. If now Fig. 44 be assumed to contain water and steam at 110 lbs. absolute pressure, and the pressure in C is suddenly dropped to 100 lbs., then each pound of water will, as above shown, liberate 7 B. T. U. which will generate steam whose expansive action will precisely duplicate that of the powder gas in the last example, and eject the water violently into the steam space.

86. And, clearly, the more tubes B there are, and the longer these tubes are, the greater the quantity of water ejected and the more violent its action! Thus it becomes plain why boilers consisting of two tubs or flat drums united by many long vertical tubes, and with the steam nozzle on the upper drum like Fig. 92, or boilers with parallel drums united by such tubes, like Figs. 101, 120 and 121, prime vigorously, and cannot act otherwise.

87. If the water circuit of the boiler be so restricted that in case of a sudden drop of pressure in the steam space the water below is unable to liberate its surplus heat immediately, this will reduce the "pop-bottle" action as above described, hence reduce the intensity of the priming. This is illustrated by header designs like Figs. 30 and 35 in which a nipple connects the header to the drum above, so that these types, *other things being equal,* do not prime as badly as some others. But this merely illustrates the adage "Out of the frying pan and into the fire," because such types have excessively constricted circulation, hence steam lock their lower tubes and burn out when operated at more than moderate ratings, as shown by Figs. 37 and 45, and in Sects. 249 to 256. Of the two evils, priming is the less and is to be preferred, since there is an after-remedy for it as proved by the Kidwell boiler, but there is no way to overcome steam locking of tubes. Read in Sects. 257 to 271 some fantastic but futile schemes proposed for overcoming this vital deficiency of header designs.

88. The self evident lesson from all this, however, is that the only way to design a boiler to meet modern demands as to high ratings and dry steam is to provide a water circuit in which there is *no restriction whatever* so that high ratings are entirely feasible, and then arrange not only to dry the steam *after it is disengaged in wet condition, but to superheat it also,* as shown in Sect. 513. "Unless superheating or steam heating surface be provided, nearly all boilers will pass off with the steam some priming or entrained water."—Parsons, *Steam Boilers,* p. 122. Reference to Sect. 501 shows that not *nearly all,* but *actually all* boilers without such superheating surface, do this. "The evident trend of general steam practise is toward the use of some degree of superheat."—R. P. Bolton, in *Superheat and Furnace Relations,* A. S. M. E. Transactions, 1907. "A boiler attached to a steam engine, and especially when fuel is costly and *efficiency important,* should have some superheating surface if practicable."—Thurston, *Manual of Steam Boilers.* The Kidwell boiler meets this requirement to the letter as shown in Sects. 513 to 527.

89. Losses Due to Wet Steam. Parsons, in his *Steam Boilers,* p. 122 says "Steam containing less than 2½ per cent of moisture may be said to be 'commercially dry'." That this allowance is extremely low is shown by the results given on page 23 of *A Study in Boiler Losses* by Prof. A. P. Kratz, Bulletin 78, University of Illinois Experiment Station. This gives the results of 24 tests made with a view of determining how to operate the boilers shown in Fig. 91 to produce the best results, and as a mean of these tests the steam showed a quality of 0.9717, hence a moisture content of 2.83%,

when operating at an average of only 101.24% of rating. At higher ratings the results would have been worse, of course. As confirming this, note Figs. 35 and 36 and what is said of them in Sects. 75 and 76. Reference to the original record there cited shows that 40 tests were made, during which this boiler developed an average of only 76.37% of its nominal rating, yet the steam contained an average of 1.94% of moisture. How much greater the moisture content would be if the boiler were run at 150% to 200% of rating is left to the judgment of the reader.

Yet this general design of boiler referred to in each of the above cases is claimed to be superior to others as to delivering dry steam, as stated in Sect. 87, therefore other designs would on the average give even a larger content of moisture than above recorded.

90. Edge Moor Iron Co's. catalog of 1913, p. 61, says:—"Dry steam at the engine * * * is very different from the *commercially dry* steam at the boiler, as this contains from 1 to 3% of water in entrainment, to which must be added what will be condensed in the steam mains, prior to its use at the engine." The catalog of Foster Marine Boiler Corporation, p. 29, states that "Boilers fitted with the ordinary slotted or drilled dry pipes frequently pass 2 to 5% of moisture when the ship is rolling in a moderately heavy sea." And some land boilers pass as much, or far more, when they do not happen to be rolling. Cases are not infrequent in which to overcome much trouble superheaters have been installed, yet the quantity of water carried over was such that the superheater was literally "drowned out" and could not evaporate this deluge of water, much less produce superheat. A case of this kind recently occurred, and this Company is now reconstructing the boilers in question, as stated in Sect. 363. Recently we saw results of a test on a boiler of the same design for which the maker vigorously claims that the steam is always *absolutely dry*. The test showed an average of *over 4% of moisture!* We have known boilers of good standing to show 6% of moisture steadily in spite of all the builder could suggest as to reducing the amount. Long experience has shown that few suspect the extent to which their boilers carry water over into the mains. Note the case reported in Sect. 520. Every pound of such water causes a considerable loss as will now be shown.

91. In *Superheated Steam and Superheaters* delivered before The National Association of Cotton Manufacturers Dr. D. S. Jacobus, in reply to a request to state the advantage of superheated steam, said:—"If you get superheat in any way that does not reduce the combined boiler and superheater efficiency below that of a saturated steam boiler* the superheat will be all to the good as to getting economy. *The first few degrees that you may get are worth more than the others, because it helps out by eliminating the wastes of drips.* The presence of 1% of moisture in the steam used by a steam turbine decreases the economy by 2%, which shows the necessity of eliminating drip water in this class of work." Later he again says, "As I have already stated, the greatest gain, *especially when actual plant conditions are considered is in the first few degrees of superheat.*"

92. This is confirmed in an editorial on *The Value of Dry Steam,* in *Power,* April 23, 1912, thus:—"*The first few degrees of superheat,* the change from somewhat wet to positively dry steam, has an effect upon turbine efficiency *out of all proportion to the difference* in heat contents, or 'available' energy." This writer then points out the serious consequences of wet steam carrying mud and grit over into the engine, (for which see Sect. 534) and continues:—"It behooves one, therefore, when buying a boiler, or considering boiler and engine performance, to take into account the *kind of steam* in question. A boiler may get rid of 12 lbs. of water for each pound of coal burned, but is the 'stuff' which it delivers all steam? And it is not enough, for practical consideration, that this evaporation should be reduced to the equivalent evaporation in dry steam, for the boiler which delivers its steam practically dry is a good deal more than 5% better for the man who is going to drive an engine with it, than a boiler which delivers a mixture of 95% of steam and 5% of moisture." And if the steam is more than "practically" dry the results will be just that much better of course.

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*A superheater increases the boiler efficiency somewhat. "It is common practise in Great Britain to guarantee 1 to 1½% greater efficiency for a boiler equipped with a superheater over that for a boiler not so equipped."—*Steam Superheaters,* in *Journal of Engineers' Club,* Philadelphia, June 1921.

93. "Though the efficiency of a superheater boiler will be higher than that of a boiler without a superheater when both are delivering the same number of B. T. U., * * * it is not the factor in the use of superheated steam from which the greatest saving results. The main factors are the *increase in efficiency of the prime mover and certain other savings* that are to be discussed in other papers."—*Steam Superheaters,* in *Journal of Engineers' Club,* Philadelphia, June, 1921. As confirming this, Mr. Geo. H. Barrus in *Experiences with Superheated Steam,* in A. S. M. E. Transaction, 1907, reported that in tests on four simple engines with the steam containing an average of only 34 deg. of superheat there was a reduction in the percentage of cylinder condensation and leakage, as compared with that found in engines using ordinary steam under similar conditions, amounting to 8%.

94. "Experience has shown that the use of steam *moderately superheated* has given the best all-around results and the most complete satisfaction."—Catalog of Foster Marine Boiler, p. 27. "The steam rate of a turbine is improved 1% for each 6 to 10 deg. of superheat."—*Power,* Sept. 27, 1921, p. 492. Also note the opinion of Mr. Bruno V. Nordberg quoted in Sect. 520. While turbines are mostly referred to above, a corresponding improvement is effected if engines are used. See *Power,* June 1, 1920, p. 895. Also see *Water in Steam Engine Cylinders* and *Hazards of Wet Steam,* in *Power,* December 27, 1921.

In *Saving Coal in Steam Plants by Using Superheated Steam,* by Babcock & Wilcox Co., pp. 10 and 11, it is stated that of the savings possible by using superheat the maximum part is due to the first 50 deg. of superheat used. Mr. A. J. Wood, discussing *Refrigerating Plant Efficiency,* by V. J. Azbe in A. S. M. E. Transactions for 1918 gave a table showing steam consumption of engines operating from ⅛ to 1¼ load, varying from 13.8 lbs. to 22.5 lbs. per hour, without superheat. He gave another table showing the savings due to different superheats and says "Note that the reduction in steam consumption is the greatest for the first 50 deg. of superheat, which is 1¾ lbs. per hour, whereas the 50 deg. of superheat above 150 deg. reduces the steam consumption only ¼ lb." Or otherwise expressed, the saving with 250 deg. of superheat seems to be not quite double the saving for the first 50 deg., hence the first 50 deg. are worth more than the next 200 deg. of superheat.

95. It is pertinent to observe here that Kidwell boilers, when stoker fired, can be so baffled as to deliver from 30 to 50 deg. of superheat, and have produced higher than that. *The saving thus effected does not cost the purchaser one dollar above the price of a wet steam boiler of the better grades as to design, material and workmanship!* See Sect. 99.

96. Percentage of Loss Due to Wet Steam. Later investigation has shown that the loss for each 1% of moisture in the steam is 2% in a compound engine; somewhat higher in a turbine, probably 3%; and 4% in a plain slide valve engine. On this basis, steam "commercially dry" as above defined by Parsons will cause a clear loss of 5, 7½, or 10%, and if the moisture content is larger, as it frequently is, the loss will be greater.

97. Practical Illustration. A certain plant contains a Kidwell boiler, and a sinuous header type of boiler like Fig. 30, both of about 400 HP. nominal rating. These are used alternately, under identical conditions. Coal costs $3.50 per ton. The Kidwell boiler shows a fuel saving of $11.00 *or more* per day over the other type.* This is due largely to the fact that it delivers superheated steam! If this amount be capitalized, it will be clear that wet steam boilers cause a large and unsuspected loss. Boiler purchasers so seldom realize the seriousness of this that an actual example will be useful in bringing the matter home to them.

98. Assume a 500 HP. boiler working at rating 320 days per year, 12 hours per day, with coal costing $7.00 per ton and of such quality that 3½ lbs. are needed per boiler HP. per hour. The cost per annum of this coal will be $23,520.00. Of this a boiler delivering wet steam into a good compound engine will lose 5%, or $1,176.00; or $1,764.00 if a turbine be used; or $2,352.00 if a slide valve engine is operated. Capitalize these amounts at only 6%, and the result will be $19,600.00, $29,400.00 and $39,200.00 respectively. If the boiler works more

*Over one year after the above was written the owner of the two boilers referred to ran each one 55 days to obtain exact data as to performance. The Kidwell boiler showed a fuel cost per KWH 17.6% less than the other boiler.

hours or coal costs more than assumed then the showing will be proportionally worse.

99. These latter figures represent merely the *preference* which a boiler that gives steam dry and somewhat superheated should receive *over and above* the price of a boiler which gives wet steam. Since even the lowest of these sums is more than necessary to purchase a boiler which not only does give steam dry and somewhat superheated, *but is otherwise far superior to the others, any one can see that it would be a far better investment to purchase such boiler than to accept gratis a boiler which delivers wet steam!* And further, that while many purchasers willingly pay the price necessary for a good superheater simply to get rid of moisture, a boiler which delivers steam dry and somewhat superheated will of itself do that and save more than 50% of the total gain due to a superheater, and such saving can be got at practically no additional cost by selecting the proper design of boiler. See Sects. 101 and end of 520 for typical cases. And where a superheater is really needed, as it always is in any plant operating engines or steam turbines with a view of obtaining the maximum economy (see Sect. 521), its efficiency and degree of superheat are enhanced just so much more if the steam delivered to it is dry to begin with, and the danger of scaling the superheater tubes and burning them is entirely overcome. See Sects. 534 to 536 for additional information.

TABLE 1.

MEAN SPECIFIC HEAT OF SUPERHEATED STEAM.

Gauge Pressure. — Pounds per Square Inch.	Superheat, Degrees Fahr., 50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°
35	.532	.527	.523	.520	.517	.515	.513	.510	.509	.508	.507	.505	.504	.503	.502	.501
40	.536	.531	.527	.524	.521	.518	.516	.514	.513	.511	.509	.508	.507	.506	.505	.504
45	.540	.535	.530	.527	.524	.522	.519	.517	.516	.514	.512	.511	.510	.509	.508	.507
50	.544	.539	.534	.531	.528	.525	.523	.521	.519	.517	.515	514	.513	.511	.510	.509
55	.547	.542	.538	.534	.531	.528	.526	.524	.522	.520	.518	.517	.515	.514	.513	.512
60	.551	.546	.542	.538	.535	.532	.529	.527	.525	.523	.521	.519	.518	.516	.515	.514
65	.555	.549	.545	.541	.538	.535	.532	.530	.527	.525	.523	.522	.520	.519	.517	.516
70	.558	.553	.548	.544	.541	.538	.535	.532	.530	.528	.526	.524	.523	.521	.520	.518
75	.561	.556	.551	.547	.544	.541	.538	.535	.533	.530	.528	.527	.525	.523	.522	.520
80	.565	.559	.554	.550	.547	.543	.540	.538	.535	.533	.531	.529	.527	.525	.524	.522
85	.568	.562	.558	.553	.550	.546	.543	.540	.538	.535	.533	.531	.529	.527	.526	.524
90	.571	.566	.561	.556	.552	.549	.545	.543	.540	.537	.535	.533	.531	.529	.528	.526
95	.575	.569	.564	.559	.555	.551	.548	.545	.542	.540	.537	.535	.533	.531	.529	.528
100	.578	.572	.566	.562	.557	.554	.550	.547	.544	.542	.539	.537	.535	.533	.531	.530
105	.581	.575	.569	.564	.560	.556	.552	.549	.546	.544	.541	.539	.537	.535	.533	.531
110	.584	.578	.572	.567	.562	.558	.555	.551	.548	.546	.543	.541	.539	.536	.535	.533
115	.587	.580	.574	.569	.565	.561	.557	.553	.550	.548	.545	.543	.540	.538	.536	.534
120	.590	.583	.577	.572	.567	.563	.559	.556	.552	.549	.547	.545	.542	.540	.538	.536
125	.593	.586	.579	.574	.569	.565	.561	.558	.554	.551	.549	.546	.544	.541	.539	.538
130	.595	.588	.582	.576	.571	.567	.563	.560	.556	.553	.551	.548	.545	.543	.541	.539
135	.598	.591	.584	.578	.574	.569	.565	.561	.558	.555	.552	.549	.547	.544	.542	.540
140	.601	.593	.586	.581	.576	.571	.567	.563	.560	.556	.554	.551	.548	.546	.544	.542
145	.603	.596	.589	.583	.578	.573	.569	.565	.561	.558	.555	.552	.550	.547	.545	.543
150	.606	.598	.591	.585	.579	.575	.571	.567	.563	.560	.557	.554	.551	.549	.546	.554
155	.608	.600	.593	.587	.581	.577	.572	.568	.565	.561	.558	.555	.553	.550	.548	.545
160	.611	.602	.595	.589	.583	.578	.573	.570	.566	.563	.560	.557	.554	.551	549	.546
165	.613	.605	.597	.591	.585	.580	.575	.571	.568	.564	.561	.558	.555	.552	.550	.548
170	.615	.607	.599	.593	.587	.582	.577	.573	.569	.565	.562	.559	.556	.554	.551	.549
175	.618	.609	.601	.594	.588	.583	.578	.574	.570	.567	.563	.560	.558	.555	.552	.550
180	.620	.611	.603	.596	.590	.585	.580	.576	.572	.568	.565	.561	.559	.556	.553	.551
185	.622	.613	.605	.598	.591	.586	.581	.577	.573	.569	.566	.562	.560	.557	.554	.552
190	.625	.615	.607	.599	.593	.587	.583	.578	.574	.570	.567	.564	.561	.558	.555	.553
195	.627	.617	.608	.601	.595	.589	.584	.579	.575	.571	.568	.565	.562	.559	.556	.554
200	.629	.619	.610	.602	.596	.590	.585	.580	.576	.572	.569	.566	.563	.560	.557	.555
205	.631	.621	.612	.604	.597	.592	.586	.582	.577	.573	.570	.567	.564	.561	.558	.555
210	.633	.623	.613	.605	.599	.593	.588	.583	.578	.574	.571	.568	.565	.562	.559	.556
215	.635	.624	.615	.607	.600	.594	.589	.584	.579	.575	.572	.568	.565	.562	.560	.557

Long after the above was written a striking confirmation of it resulted from an installation this Company made in Milwaukee. Two sinuous header boilers without superheaters were replaced by two Kidwell boilers without superheaters. The fuel saving alone amounts *in one year only* to slightly more than the contract price of the Kidwell boilers delivered at the plant with services of erecting mechanic included.

100. The Specific Heat of Superheated Steam. As this is sometimes needed in computations, we present Table 1, which is reproduced

from the paper on *Superheated Steam and Superheaters* cited in Sect. 91 and gives the mean of the values as computed from formulas of Knoblauch and Jakob of Berlin, and Prof. Carl C. Thomas of Johns Hopkins Universtiy. The different formulas give results which disagree slightly, but the variation is immaterial in any but the most refined computations. The greatest discrepancy in the tables is in the values for low superheats. If greater accuracy is necessary, Marks and Davis's *Steam Tables and Diagrams* may be consulted. Example:—What is the mean specific heat of superheated steam at 150 lbs. gauge pressure, and 80° of superheat? 150 lbs. gauge = 165 lbs. absolute. Referring to Table 3 in Marks and Davis, p. 48, we find that for these conditions the *total heat* of the steam, including superheating, will be 1241.5 B. T. U. From Table 2, p. 19, of the same work the total heat of saturated steam of 165 lbs. absolute pressure is 1195 B. T. U., hence 1241.5—1195=46.5 B. T. U., which is the amount of heat necessary for superheating this steam 80 degrees, therefore the *mean* specific heat is 46.5÷80=0.58125, whereas our Table 1 gives 0.585, which indicates the difference between the two sources.

101. Advantage of Moderate Superheat in Industrial Processes. Sects. 90 to 95 show that when steam drives prime movers the first few degrees of superheat are worth more than the others of higher temperature. In addition, moderate superheats effect great savings in sundry industrial processes. Only one example will be given here.

In the manufacture of paper pulp an improvement out of all proportion to the cost results if the steam admitted to the digester contains 15 to 40 deg. of superheat. When wet steam is admitted it dilutes the mixture and affects the action materially. As the amount of deleterious water thus admitted is not known the process approximates guess work. If dirt is carried over by the steam as described in Sect. 534, that discolors the pulp, often to an extent that is serious.

With superheated steam not only are dilution of the mixture and discoloration of the product avoided, but the superheat acts as a bleacher, and produces a whiter pulp than obtainable with wet steam, even if it be clean.

In consequence, digesters supplied with superheated steam from Kidwell boilers have produced a whiter and better pulp from hemlock than was obtained from spruce when using ordinary wet steam.

It has also been proved that for such work 40 to 50 deg. of superheat *is the highest that may be used,* as more superheat produces paper which, for a given weight, is thicker and bulkier, and of less tensile strength than when the lower superheats are used.

The Kidwell boiler delivers steam sufficiently superheated for all the requirements of the above described process, hence buyers obtain that advantage without extra cost.

102. A moderate superheat also eliminates leaks in the joints of the steam pipes, with their disagreeable dripping of hot water, and likewise reduces the amount of condensation in the piping, since the conductivity of superheated steam is less than that of saturated steam. It similarly reduces the leakage and "weeping" through the rod glands, thus saving both rod and packing. Other important advantages are listed in "Radiation Losses and the Advantages of Using Superheated Steam" in *Power Plant Engineering,* January 1, 1921.

103. Superheated Steam May Carry Entrained Water. This is not generally known to those who have not had actual experience with superheat, but it has long been a proved fact. A typical illustration of it was given to this writer by the late Mr. John P. Sparrow, Chief Engineer of New York Edison Co. Certain tests were made on boilers in which the connection between boiler steam space and the superheater inlet extended down through the water space in the upper drum and the bottom drum plate, thence to the superheater. One boiler showed an impossible evaporation practically double that of the others. Investigation disclosed a crack in this pipe below the water line in the boiler drum, and through this a stream of water was pouring through superheater, main, and turbine, yet its presence was not even suspected. The thermometer registered the usual superheat and thus gave no indication that nearly 50% of the material flowing was entrained water.

104. It is not infrequent to find that in plants using boilers so designed that the steam occasionally picks up slugs of water, such water passes through the superheater without being broken up and evaporated, and therefore separators have to be installed in the engine or turbine connection, even though the steam is superheated and the thermometer so indicates.

That superheated steam can and does often convey water is stated in *Steam Superheaters* by Babcock & Wilcox Co., 1914 Edition, p. 9, but we are unable to quote this passage as permission to do so was not granted by publishers of that book.

See a pertinent application of the above stated fact at the end of Sect. 520.

105. Boiler Efficiency. This is a subject on which a vast deal has been written, most of which is deficient because it fails to explain how to generate steam at the lowest cost. Many vital considerations are often not mentioned, and after reading most of the current trade literature one could easily conclude that the whole subject involved only the *efficiency as referred to fuel,* and that too when the boiler is clean and working under ideal conditions. Therefore, it must be clearly understood that what the plant operator wants to ascertain is *how to produce the final results at the least expense,* or how to save MONEY, rather than steam, coal, or anything else. See Sect. 25(1). We wish to save all these items and any others possible, but only when the value of the thing saved is greater than the cost of saving it. "When the point in efficiency is reached where the saving in fuel costs will no longer pay a fair return on the capital investment and other charges necessary to obtain higher economy, *the most economical condition has been reached and any further improvement in efficiency only increases the cost of a unit of power delivered to the consumer!* This is an important factor, for in the final analysis the consumer's chief interest is how cheaply a reliable service can be obtained and not how efficiently fuel is utilized."—*Power,* December 6, 1921, on *Three Factors in Power Plant Design.* "The true measure of efficiency of a boiler installation, in the last analysis, is its cost divided by its evaporative capacity, and *only indirectly by efficiencies in terms of its thermal ability to convert heat into steam.* * * * High thermal efficiency *is secondary* and only justified when evaporative demands are such as to reduce fixed charges to a point where reduction in fuel cost becomes attractive."—V. Z. Caracristi in *Combustion,* Aug, 1922. Illustration:—Occasionally reports appear that some boiler has shown a fuel efficiency of 85 to 90%, with the implied inference that such result is of course worthy of emulation. This is not always true. Any competent designer can attain such results when burning good fuel *provided he ignores the cost of getting these results.** If such cases be dissected and figured as to Efficiency of Capital it will develop that *they do not pay.* This will appear from Sects. 201, 202, 208, and 219 to 222.

106. Accordingly, there are *two entirely distinct kinds of efficiency* to be considered with reference to boilers. The first is its efficiency as an absorber of heat, or its fuel efficiency about which so much has been written! The second is the *final result efficiency,* or *Efficiency of Capital,* which though by far the more important of the two, is seldom referred to and less seldom appreciated. For example, the boiler shown in Fig. 35 showed a good efficiency at low ratings, yet its maximum efficiency was developed at only 56 to 66% of rating, and fell off as the load increased. It was not tested above 128% of rating, and if run at any such ratings as are common and absolutely necessary in any standard electric plant it would steam lock its lower tubes and burn them, as shown in the exposition illustrated by Fig. 45. Consequently, it clearly cannot meet modern conditions as to safe overloading, hence as an investment would not be attractive.

107. "Thermal efficiencies *in themselves have no economic value* to the owners of central power station properties, their effect on net income being only *one of a series* of items which govern operating costs, the reduction of which, as a whole, in the last analysis, is the function

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*"By applying the principles of heat transmission developed in the general discussion it would be possible to design with fair accuracy a boiler for *any desired efficiency.*"—Bulletin 18, Bureau of Mines, p. 142. On page 141 of this Bulletin this authority cites several means of increasing fuel efficiency, but strikes the keynote of the whole question by adding:—"Whether the greater investment would be sound commercial economy in most cases the authors of this bulletin do not undertake to say." Even more important than the investment item is the question of *dependability for continuous operation,* and our observation is that great complication and refinement, all items considered, do not pay. This is a clear case where the *Law of Diminishing Returns* strongly applies. See *Elements of Political Economy,* by Professor J. Lawrence Laughlin. The same consideration applies to using very high steam pressures. There is a marked tendency in certain quarters at present to urge pressures which require all special equipment, fittings, etc., but ordinary business caution will suggest that boiler purchasers will do well to await *positive proof* that such high pressures save MONEY, which is the only consideration which can justify their adoption.

of the designing and operating engineers."—V. Z. Caracristi in *Combustion*, August, 1922. Thus it is frequently possible to *increase* the efficiency of capital by *decreasing the fuel efficiency!*

108. The Coal Cost of Generating Steam. To confirm the above statement that efficiency of capital takes precedence over fuel efficiency, note that if by using a poorer and cheaper coal the fuel efficiency is reduced, but the cost of producing steam is reduced even to a greater degree, then the efficiency of capital is increased, hence money is saved. Gebhardt, *Steam Power Plant Engineering*, p. 162, says:—"The boiler, furnace and grate efficiency is only one of the many factors entering into the economical operation of the boiler plant. Different fuels may give the same efficiency under actual operating conditions, *but the ultimate economy in dollars and cents may vary considerably. The real criterion is the net cost of evaporation, taking into consideration the cost of handling the fuel, disposition of refuse, ability to handle peak loads and depreciation of grate and setting.* The common practise of comparing the performance of boilers on the 'fuel cost to evaporate 1000 lbs. of water,' is apt to lead to erroneous conclusions; thus, the cost of evaporating 1000 lbs. of water from and at 212 deg. Fah., when burning cheap bituminous screenings, may be 12 cents as against 18 cents when burning high-grade and more costly washed coal, but the freight charges, cost of handling the fuel and disposition of the ash may more than offset the gain in evaporation and the cheaper fuel may prove to be the more expensive in the

FIG. 45. SHOWING DISTORTION OF TUBES DUE TO STEAM LOCKING CAUSED BY DEFICIENT CIRCULATION

TABLE 2.

THE COAL COST OF GENERATING 1000 LBS. OF STEAM.

From *The Black Diamond*, March 20, 1920, caption "How to Buy Coal to Get Your Money's Worth." To get a true comparison the coal cost per ton should include *all items*, such as handling, stoking, removal of ashes, etc., and any other expense affected by a change from one coal to another.

Price of Coal per 2000 lbs.	Evaporation per pound of Coal from and at 212° F.																										
	5.00	5.50	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75	9.00	9.25	9.50	9.75	10.00	10.25	10.50	10.75	11.00	11.25	11.50	11.75	12.00
	Cost in Cents to Evaporate 1000 Pounds of Water from and at 212° F.																										
$1.00	10.0	9.10	8.33	8.00	7.70	7.42	7.14	6.90	6.66	6.45	6.25	6.06	5.88	5.73	5.56	5.40	5.27	5.13	5.00	4.88	4.76	4.65	4.55	4.44	4.35	4.26	4.17
1.25	12.5	11.3	10.4	10.0	9.62	9.25	8.93	8.62	8.33	8.07	7.82	7.56	7.35	7.15	6.95	6.75	6.57	6.42	6.25	6.10	5.96	5.81	5.68	5.56	5.44	5.32	5.21
1.40	14.0	12.7	11.7	11.2	10.8	10.4	9.99	9.66	9.33	9.03	8.75	8.48	8.23	8.00	7.78	7.57	7.36	7.18	7.00	6.83	6.67	6.51	6.36	6.22	6.09	5.96	5.83
1.45	14.5	13.1	12.1	11.6	11.2	10.7	10.4	10.0	9.66	9.35	9.06	8.78	8.53	8.29	8.05	7.84	7.63	7.43	7.25	7.08	6.91	6.74	6.59	6.44	6.31	6.17	6.04
1.50	15.0	13.7	12.5	12.0	11.5	11.1	10.7	10.4	10.0	9.68	9.38	9.10	8.82	8.57	8.35	8.12	7.90	7.70	7.50	7.32	7.15	6.97	6.82	6.66	6.53	6.38	6.25
1.55	15.5	14.1	12.9	12.4	11.9	11.5	11.1	10.7	10.3	10.0	9.69	9.38	9.01	8.86	8.61	8.38	8.15	7.94	7.75	7.56	7.38	7.21	7.03	6.89	6.74	6.59	6.45
1.60	16.0	14.6	13.4	12.8	12.3	11.8	11.4	11.0	10.7	10.3	10.0	9.69	9.41	9.14	8.89	8.65	8.42	8.20	8.00	7.81	7.62	7.44	7.27	7.11	6.96	6.81	6.66
1.65	16.5	15.0	13.8	13.2	12.7	12.2	11.8	11.4	11.0	10.6	10.3	10.0	9.70	9.43	9.16	8.92	8.68	8.46	8.25	8.05	7.86	7.67	7.50	7.33	7.18	7.02	6.87
1.70	17.0	15.5	14.2	13.6	13.1	12.6	12.1	11.7	11.3	11.0	10.6	10.3	10.0	9.71	9.44	9.19	8.94	8.71	8.50	8.30	8.10	7.90	7.72	7.55	7.39	7.23	7.08
1.75	17.5	15.9	14.6	14.0	13.5	13.0	12.5	12.1	11.7	11.3	10.9	10.6	10.3	10.0	9.73	9.47	9.22	8.98	8.75	8.54	8.34	8.14	7.95	7.78	7.61	7.45	7.29
1.80	18.0	16.4	15.0	14.4	13.9	13.3	12.9	12.4	12.0	11.6	11.3	10.9	10.6	10.3	10.0	9.73	9.47	9.23	9.00	8.78	8.57	8.37	8.18	8.00	7.83	7.66	7.50
1.85	18.5	16.8	15.4	14.8	14.2	13.7	13.2	12.8	12.3	11.9	11.6	11.2	10.9	10.6	10.3	10.0	9.73	9.48	9.25	9.03	8.81	8.60	8.41	8.22	8.05	7.87	7.70
1.90	19.0	17.3	15.9	15.2	14.6	14.1	13.6	13.1	12.7	12.3	11.9	11.5	11.2	10.9	10.6	10.3	9.99	9.74	9.50	9.29	9.05	8.84	8.63	8.44	8.29	8.08	7.91
1.95	19.5	17.7	16.3	15.6	15.0	14.4	13.9	13.4	13.0	12.6	12.2	11.8	11.5	11.1	10.8	10.5	10.3	9.99	9.75	9.52	9.28	9.07	8.86	8.67	8.48	8.30	8.12
2.00	20.0	18.2	16.7	16.0	15.4	14.8	14.3	13.8	13.3	12.9	12.5	12.1	11.7	11.4	11.1	10.8	10.5	10.3	10.0	9.76	9.53	9.30	9.09	8.89	8.70	8.51	8.33
2.05	20.5	18.6	17.1	16.4	15.8	15.2	14.6	14.1	13.6	13.2	12.8	12.4	12.0	11.7	11.4	11.1	10.8	10.5	10.2	10.0	9.77	9.53	9.32	9.11	8.92	8.72	8.54
2.10	21.0	19.1	17.5	16.8	16.2	15.6	15.0	14.5	14.0	13.5	13.1	12.7	12.3	12.0	11.7	11.3	11.0	10.8	10.5	10.2	10.0	9.77	9.54	9.33	9.13	8.94	8.75
2.15	21.5	19.5	17.9	17.2	16.5	15.9	15.3	14.8	14.3	13.9	13.4	13.0	12.6	12.3	11.9	11.6	11.3	11.0	10.7	10.5	10.2	10.0	9.77	9.56	9.35	9.15	8.95
2.20	22.0	20.0	18.4	17.6	16.9	16.3	15.7	15.2	14.7	14.2	13.7	13.3	12.9	12.6	12.2	11.9	11.6	11.3	11.0	10.7	10.5	10.2	10.0	9.78	9.57	9.36	9.16
2.25	22.5	20.4	18.8	18.0	17.3	16.7	16.1	15.5	15.0	14.5	14.1	13.7	13.2	12.9	12.5	12.2	11.8	11.5	11.2	11.0	10.7	10.5	10.2	10.0	9.79	9.57	9.37
2.30	23.0	20.9	19.2	18.4	17.7	17.0	16.4	15.8	15.3	14.8	14.4	13.9	13.5	13.1	12.8	12.4	12.1	11.8	11.5	11.2	11.0	10.7	10.5	10.2	10.0	9.79	9.58
2.35	23.5	21.4	19.6	18.8	18.1	17.4	16.7	16.2	15.7	15.2	14.7	14.2	13.8	13.4	13.1	12.7	12.4	12.0	11.8	11.5	11.2	11.0	10.7	10.4	10.2	10.0	9.79
2.40	24.0	21.8	20.0	19.2	18.5	17.8	17.1	16.6	16.0	15.5	15.0	14.5	14.1	13.7	13.3	13.0	12.6	12.3	12.0	11.7	11.4	11.2	11.0	10.7	10.4	10.2	10.0
2.45	24.5	22.3	20.5	19.6	18.9	18.1	17.5	16.9	16.3	15.8	15.3	14.8	14.4	14.0	13.6	13.2	12.9	12.6	12.2	12.0	11.7	11.4	11.1	10.9	10.7	10.4	10.2
2.50	25.0	22.6	20.8	20.0	19.2	18.5	17.9	17.2	16.7	16.1	15.6	15.1	14.7	14.3	13.9	13.5	13.1	12.8	12.5	12.2	11.9	11.6	11.4	11.1	10.9	10.6	10.4
2.55	25.5	23.2	21.3	20.4	19.6	18.9	18.2	17.6	17.0	16.4	15.9	15.4	15.0	14.6	14.2	13.8	13.4	13.1	12.8	12.4	12.1	11.9	11.6	11.3	11.1	10.9	10.6
2.60	26.0	23.7	21.7	20.8	20.0	19.2	18.6	17.9	17.3	16.8	16.2	15.7	15.3	14.9	14.4	14.1	13.7	13.3	13.0	12.7	12.3	12.1	11.8	11.6	11.3	11.1	10.8
2.65	26.5	24.1	22.1	21.2	20.4	19.6	18.9	18.3	17.7	17.1	16.6	16.0	15.6	15.1	14.7	14.3	13.9	13.6	13.3	12.9	12.5	12.3	12.0	11.8	11.5	11.3	11.0
2.70	27.0	24.6	22.5	21.6	20.8	20.0	19.3	18.6	18.0	17.4	16.9	16.3	15.9	15.4	15.0	14.6	14.2	13.8	13.5	13.2	12.7	12.5	12.3	12.0	11.7	11.5	11.2
2.75	27.5	25.0	23.0	22.0	21.2	20.3	19.6	19.0	18.3	17.7	17.2	16.6	16.2	15.7	15.3	14.9	14.5	14.1	13.7	13.4	13.1	12.8	12.5	12.2	11.9	11.7	11.4
2.80	28.0	25.4	23.4	22.4	21.6	20.7	20.0	19.3	18.7	18.1	17.5	17.0	16.5	16.0	15.6	15.1	14.7	14.4	14.0	13.7	13.3	13.0	12.7	12.4	12.2	11.9	11.7
2.85	28.5	25.4	23.8	22.8	21.9	21.1	20.3	19.7	19.0	18.4	17.8	17.3	16.8	16.3	15.8	15.4	15.0	14.6	14.3	13.9	13.6	13.3	13.0	12.7	12.4	12.1	11.9
2.90	29.0	26.4	24.2	23.2	22.3	21.5	20.7	20.0	19.3	18.7	18.1	17.6	17.1	16.6	16.1	15.7	15.3	14.9	14.5	14.2	13.8	13.5	13.2	12.9	12.6	12.3	12.1
2.95	29.5	26.8	24.6	23.6	22.7	21.8	21.1	20.4	19.7	19.3	18.4	17.9	17.3	16.9	16.4	15.9	15.5	15.1	14.8	14.4	14.0	13.7	13.4	13.1	12.8	12.6	12.3
3.00	30.0	27.4	25.0	24.0	23.0	22.2	21.4	20.8	20.0	19.4	18.8	18.2	17.6	17.1	16.7	16.2	15.8	15.4	15.0	14.6	14.3	14.0	13.6	13.3	13.0	12.8	12.5
3.25	32.5	29.6	27.1	26.0	25.0	24.1	23.2	22.4	21.7	21.0	20.3	19.7	19.1	18.6	18.1	17.6	17.1	16.7	16.3	15.9	15.5	15.1	14.8	14.4	14.1	13.8	13.5
3.50	35.0	31.8	29.2	28.0	27.0	26.0	25.0	24.2	23.4	22.6	21.8	21.2	20.6	20.0	19.5	18.9	18.4	18.0	17.5	17.1	16.7	16.3	15.9	15.6	15.2	15.0	14.6
3.75	37.5	34.0	31.2	30.0	28.8	27.7	26.8	25.8	25.0	24.1	23.4	22.7	22.1	21.4	20.8	20.3	19.7	19.2	18.8	18.3	17.9	17.4	17.0	16.6	16.3	16.0	15.6
4.00	40.0	36.3	33.3	32.0	30.7	29.6	28.6	27.6	26.6	25.8	25.0	24.2	23.5	22.9	22.2	21.6	21.1	20.5	20.0	19.5	19.0	18.6	18.2	17.7	17.4	17.0	16.6
4.50	45.0	40.9	37.5	36.0	34.6	33.3	32.1	31.0	30.0	29.0	28.2	27.4	26.4	25.8	25.0	24.4	23.6	23.0	22.4	22.0	21.4	21.0	20.4	20.0	19.6	19.1	18.7
5.00	50.0	45.2	41.6	40.6	38.4	37.0	35.8	34.4	33.4	32.2	31.2	30.2	29.4	28.6	27.8	27.0	26.2	25.6	25.0	24.4	23.8	23.2	22.8	22.2	21.8	21.2	20.8

end. Each installation is a problem in itself and all local influencing conditions must be considered before maximum economy can be effected. In general, for plants equipped with coal and ash handling machinery and adjacent to a railroad or to water transportation, the cheaper the fuel per pound of combustible the lower will be the ultimate cost of evaporation."

To permit rapid comparisons of the cost of generating 1000 lbs. of steam Table 2 is presented, but the footnotes thereto should be carefully read and understood.

109. Need of Caution When Interpreting Fuel Efficiency Reports. Such an extraordinary amount of nonsense has been written about fuel efficiencies that it is essential to show how easily these may mislead those who do not consider all the factors involved. For example, see *Steam,* p. 36, second full paragraph, in which the writer gravely informs us that the boiler

FIG. 46. VARIATION OF EFFICIENCY WITH TIME IN SERVICE

he is lauding is the *ne plus ultra* of perfection and the utmost any other designer can hope for is to *persuade the public* that he has "Something else just as good." A careful perusal of these pages and an analysis of the design he refers to, in accordance with the facts herein set forth, will quickly show that this and similar claims are based on hopes or romance rather than technical facts.

110. A result obtained from a test under ideal conditions and with a clean boiler and everything tuned up to meet the occasion proves absolutely nothing, *except what can be done by that operator with that boiler under identical conditions!* It no more represents what that boiler will do under regular operating conditions than the fact that it is raining today in New York means that it is doing the same everywhere else, yet buyers are constantly misled into thinking that because some boiler is alleged to have shown a high efficiency under such conditions it is a good one to buy. This error can be exposed quickly. In Fig. 46 let AC and AE represent the fuel efficiencies of two boilers when clean. At first glance one would conclude that the boiler giving the result AC is the better, but suppose that after each boiler operated up to the time when cleaning is to be done, another test then showed up the efficiencies BF and BD. Then clearly the boiler producing the line EF is superior to the other, though at the start it did not so appear. Now a drop of efficiency such as shown by line CD can easily be produced by scale on the tubes, deposit of mud in upper tubes because of back boiling, leakage of gaskets under hand hole plates, etc., *all of which things happen with far greater frequency in header types of boilers than in others,* and thus cause them to drop off in efficiency faster than in the others! This will now be proved. But first it is necessary to point out two other items of supreme importance.

111. No fuel efficiency result as determined by a test as above described gives any indication of the *kind of steam turned out of the boiler nozzle, or whether such steam will produce efficient results in the engine or not!* Even were the fuel efficiency as above determined apparently high, the advantage of it will instantly vanish *if the steam turned out is wet,* as shown in Sects. 89 to 99. Thus the final *commercial efficiency* may be, and often is, quite low, and that is the only efficiency which interests the man who pays the bills! This fact cannot be too strongly stressed, as it is very rarely realized.

112. If an engine is properly adjusted to operate under a given load, at a given steam pressure, with steam of a fixed quality, it will continue to operate indefinitely at the same efficiency without other attention than that necessary to keep it in condition. This is not true of a boiler, because the quality and temperature of the feed water, amount and condition of the fuel used, quantity of air supplied, intensity of the draft, condition of the heating surface, and sundry other items, are subject to rapid changes which affect the results. See last part of Sect. 390. Few consider the extent to which such fluctuations influence the performance of the particular boiler design used, since unquestionably not all boilers are equally affected by such factors. Therefore, when it is claimed that a certain efficiency was obtained under certain conditions, it is equally important

to consider the relative difficulty of different designs as to maintaining such conditions in actual daily operation.

Another point to be considered is the degree of *reliability* of tests, and both the probable percentage of error, and to what extent they may have been faked. See Sects. 159 and 178 to 180 as indicating the difficulty of measuring certain factors. Then see Sects. 299 and 366 for an illustration of how other factors may be juggled by an expert manipulator, or not recognized and taken into account by a conscientious operator.

For the above and other reasons our final belief based on long observation is that unless the steam generated by the boiler is passed directly through a surface condenser, then accurately weighed, no boiler test made in the usual way, and where solid fuel is used, can be considered accurate within 4% to 5%, and in many cases the margin of error is undoubtedly greater.

113. Quantity and Effect of Impurities in Feed Water.* Approximately pure feed water is rarely obtainable. Of the various impurities found, from 90 to 98% consist of carbonates and sulphates of calcium which fortunately precipitate at a temperature of 302 deg., or 55 lbs. gauge pressure, so that in a *boiler properly designed* these can be thrown down before the water reaches the tubes over the fire.

Waters containing 8 grains or fewer per gallon are considered excellent, those with 20 grains or more are bad, and those containing larger quantities should be purified if possible. Technical Paper 218, Bureau of Mines, on *Boiler Water Treatment,* contains some excellent information on this subject. Also see *Water Treatment for Boilers* in *Mechanical Engineering,* Sept. 1921, p. 597, and footnote to Sect. 83.

114. Parsons, *Steam Boilers,* p. 311, says:—"The quantity of matter held in solution is generally between 20 and 40 grains per gallon, but often exceeds 200 grains. To appreciate the effect, imagine a boiler evaporating 3000 pounds of water per hour (100 HP.). This means an evaporation at the end of 4 weeks, of 6 days of 10 hours each, of 720,000 pounds, or 86,746 gallons. Assuming the water to contain 20 grains per gallon, this amount would carry into the boiler and leave as scale 1,734,920 grains, or 247.8 pounds. Taking the specific gravity of the scale as 3, this quantity would be equivalent to 1.32 cu. ft., or enough to cover 750 sq. ft. of heating surface with scale 0.02112-inch thick, or over ¼-inch per year. In addition to the substance in solution, nearly all waters carry clay and other earthy matters in suspension, which will greatly increase the above figures." The earthy matter above referred to often occurs in such quantity that if not removed it may accumulate past the danger point in less than a week, and in some mining districts we have seen cases where a boiler could not be operated longer than *three days* without a shut down for cleaning!

115. No matter what the design of the boiler may be, this material *must go somewhere,* and the problem is to make it *go to and stop at* the place in the boiler where it will do the least harm. An incredible amount of twaddle has been written about rapid *circulation preventing scale formation,* hence this error must be disposed of beyond resurrection. Even if circulation could prevent the impurities from settling or depositing, *they would still remain in the boiler,* and by the steady evaporation of the water these would so concentrate that in time there would be no room left for water, hence the absurdity of this belief!

"Some water tube boilers, now dead and gone, were some years ago put on the market, which had no facilities for the removal of scale. It was claimed by their promoters that they *did not need any, because their circulation was so rapid.* Every few years boilers of these types are re-invented, and the same claim is made for them, that their rapid circulation pre-

*"A modern boiler is not merely a basin in which water is converted into gas (vapor), but a receptable for the mineral impurities contained, in greater or less quantities, in all natural waters even when softened. The boiler is in reality an autoclave (i. e., a closed vessel for boiling water) in which chemical solutions are concentrated and partially evaporated at high temperatures and pressures, and should be looked upon as a chemical factory in which various chemicals are produced during the conversion of ordinary water from an initial temperature of, say 60° F. into steam often highly superheated. Some of these reactions affect the steaming capacity of the boiler and others affect the metal of which it is constructed. If these reactions are not properly understood and properly controlled much damage may be done to the metal itself, even if that damage be not sufficient to cause explosion or render the boiler useless for steam-raising purposes."—Preface to Paul's *Boiler Chemistry and Feed Water Supplies.* Also see *Water Purification for Boiler Feed,* by B. T. Crolius in *National Engineer,* March and April, 1922.

vents the formation of scale.* The fact is that if there is scale forming material in the water it will be deposited when the water is evaporated, and no amount or kind of circulation will keep it from accumulating on every part of the boiler and in every kind of tubes, vertical, horizontal and inclined. The nearly vertical circulating tubes of a water tube boiler, in which the circulation is 9 times as fast as the average circulation in the inclined tubes, sometimes have been found nearly full of scale; that is, a 4-inch tube had an opening in it of less than 1-inch diameter; this was due to carelessness in blowing off the boiler, or exceptionally bad feed water, or in the up-comer nipples. And it is clear that the water must flow many times faster in headers like in Fig. 30 than in the tubes. Yet these headers also frequently accumulate scale heavily, as shown in Sects. 145 and 146, and the photograph on page 599 of *Mechanical Engineering* for September, 1921 will confirm this. Therefore, *water speed alone does not and cannot prevent scale formation,* notwithstanding frequent assertions to the contrary, even in the latest boiler publications which pretend to be up to date and accurate. Water speed will prevent the dropping of sand, sediment, or other solids *which do not form scale,* as below shown, which

TABLE 3.

LOSSES DUE TO SEDIMENT AND SCALE.

Character of scale.	Thickness.	Composition.	Loss of efficiency.
	Inch.		*Per cent.*
Hard	1/50	Mostly carbonate	9
Soft	1/32	.....do	7
Hard	1/32	.....do	8
Soft	1/25	.....do	8
Hard	1/25	Mostly sulphate	9
Do	1/20	.....do	11
Soft	1/16	.....do	10
Do	1/16	Mostly carbonate	11
Do	1/16	.....do	12
Hard	1/16	.....do	12
Soft	1/11	.....do	15
Hard	1/9	Mostly sulphate	16

both. If circulation would prevent scaling at all, it would prevent it here."—Kent, *Steam Boiler Economy,* p. 298.† It also could be due to improper proportion of the circulative passages in the boiler, for which see Sect. 145. For example, single cross drum header and water leg types with nipples connecting the drum to header below, as in Fig. 68, are frequently found to plug many of these nipples partly or wholly with scale. This is due to the fact that as soon as the feed enters, the separation of the impurities begins, and these aggregate into scale which promptly adheres to the surface of the nipples in spite of the fact that here the water speed is greater than elsewhere in the circuit except action is of supreme importance in boiler operation, but this does not apply to scale.

Besides the solids above referred to, all natural waters contain air and carbonic acid gas which also are detrimental. See Sects. 134 to 136 for further particulars.

116. Losses Due to Scale and Sediment. Figures purporting to give a definite percentage of heat loss corresponding to given thickness of scale are merely rough estimates subject to great error because they ignore density.

The following from pp. 29 and 31 of Bulletin 1752 cited in footnote to Sect. 83 seems more reliable than any similar data available, though this also is necessarily approximate.

*For a remarkable and typical illustration of this see catalog of Howden Boiler Co., Helen St., Glasgow, Scotland.

†I. e., the nipples connecting headers and drums in boilers like Figs. 18 to 30. Kent's statements was written years ago before it became common to make boilers many tubes high, as shown in Fig. 35. In these the relative velocity of water through nipples as compared with the other tubes is far greater than 9, for which see Sect. 75.

"The most important effect of scale is due to the fact that it is a wonderful heat insulator. Its chemical composition seems to have little to do with its heat insulating power, the big question being the density or mechanical structure of the scale. A series of experiments by Professor Schmidt of the University of Illinois gave the results in Table 3.

"Regarding the heat insulating effect of scale, this statement is made by E. W. Fiske:—'If the rate of evaporation is low, and especially if the scale in question is in a part of the boiler or its auxiliaries where the flue gases have lost some of their heat, and the feed water has not reached its maximum temperature, the scale will be damp to some extent. If, however, the rate of evaporation is high, the body of the scale will be dry, or contain nothing but highly heated superheated steam, and in this condition it approaches the condition of a dry pipe covering, and we have an excellent insulator, which, considering its thickness, compares favorably with pipe coverings in general. This may account for the fact that tests made at high rates of evaporation generally show decided loss on account of scale.'

117. "Another author has summarized the cost due to scale as follows:—'The extra coal consumed; the cost of extra boilers to make up for the limitations on boiler capacity imposed by scale-forming water; the cost of extra boilers in order to provide stand-by for cleaning; the cost of cleaning, retubing and repairing boilers; the cost of firing boilers put out of service for repairing and cleaning; the depreciation on boilers, the life of which is greatly shortened by corrosion, pitting, cleaning, expansion and contraction strains, and other evil effects of scale-forming feed water.'"

Another consequence of scale is that it decreases the effective tube bore, and in header and nipple types this causes serious trouble, as noted by Kent's statement in Sect. 115.

The moral of this is plain: *avoid feeding dirty water into boilers as far as possible.* Use the boiler as a steam generator and not as a water purifier. No detail of plant operation confirms better than this the ancient maxim that "A stitch in time saves nine." The serious explosion described in Sect. 538 illustrates this.

118. Anyone in doubt as to the wisdom of investing the money necessary to provide effective equipment for cleaning boilers should read *Cleaning Water Tube Boilers* in *Power,* Feb. 28, 1922, and note a case in which scale had been permitted to accumulate to such extent that "the tubes burned away where they were laid in the brickwork at the rear of the furnace, *so that only the scale held against the boiler pressure!* About 40 tubes had to be replaced." After the cleaning was done the coal consumption dropped from 90 to 55 tons a day!

The above is not an unusual case. We have seen some in which tubes were burned away and the end of the stumps were plugged with scale which acted as a stopper and held against the steam pressure!

Technical Paper 218, Bureau of Mines, *Boiler Water Treatment* gives on page 8 a list of examples of losses due to scale which cannot fail to bring home to every boiler owner the need of serious consideration of this subject.

119. How Boiler Design Influences the Point of Deposit of Sediments. The power of water for transporting or pulling solids along with it varies with the *sixth power of its velocity,* that is, if the water speed be doubled or tripled its carrying capacity will be multiplied 64 or 729 times, and so on for higher speeds. In all boilers the water travels faster in some part of its circuit than others, hence its transporting power will vary accordingly, so that when the slower speeds are reached, matter which was carried at higher speeds must be precipitated. If this fact is properly applied in boiler design it is possible to prevent the precipitates from reaching the tubes over the fire.

120. Since of the impurities generally found in feed waters from 90 to 98% will be precipitated when subjected to temperatures exceeding 302° F., these will settle into a mud drum where they can do no harm and be easily blown out, *if they are permitted to do so, instead of being swept along into the tubes by water traveling at high velocity!* In a longitudinal drum boiler like Figs. 33 and 47 the distance from the feed pipe end to the top of the down-comer is available for causing such precipitation, but unfortunately the moment the water reaches the down-comer in such boilers *its velocity increases,* hence its power of transporting solids increases to the degree above stated, therefore the impurities, instead of being permitted to settle, are swept along with increasing speed, hence, since in horizontal type of boilers the water enters the lower tube faster than in the others, *the greatest proportion of the precipitates is swept into the bottom tubes, which is exactly*

the place where they will do the greatest harm, since these tubes are exposed to the furnace temperature! This is proved, not only by the frequent tube failures due to burning in such types, *but also by the heavy deposits of mud in the upper tubes when back-boiling occurs,* since such mud can reach this point only after first going through the lower tubes! Note Sects. 254 and 255. And, if the boiler is not driven hard enough to cause back-boiling, this material keeps going around and around in the water circuit until concentration proceeds to such a point that it can no longer be held in suspension; then it is left as a residue *where the water evaporates the fastest, which is the most dangerous place in the circuit.* Thus *the total deposit becomes the sum of the scale and precipitate,* so that its thickness rapidly increases, and the danger of burning the tubes is multiplied manyfold. *The action as here described is characteristic of all horizontal water tube boilers, and is inherent in the design, hence cannot be overcome.* When the boiler cools, this aggregation of incrustation frequently chips off in places, which explains the citation from Hutton in Sect. 122 and the "loose scale" referred to by Jacobus in Sect. 250 and Weaver in Sect. 253. This trouble can be lessened by providing in the steam and water drum a separate feed drum with its own blow off pipe as in Fig. 67, but such drums are too small to remove more than part of the precipitates, and greatly obstruct the interior of the main drum when cleaning or inspection is necessary, hence are objectionable.

121. Yet this serious cause of reduced Efficiency of Capital can be largely overcome by correct design of the boiler. The remedy for it is to enter the feed at the right place, as shown in Sect. 133, and to provide the greatest possible travel for the water from the feeding point to where it enters the tubes subjected to the greatest heat, and to make the water speed at this part of the circuit slower than elsewhere so as to give the precipitates time to form and settle.* Now, complete the process by supplying a mud drum of *ample volume* (not a mere piece of pipe 7 by 7 inches or thereabouts!) and located *in the water circuit and at the bottom of the down-comer,* so that the precipitates readily drop into it as the water entering this drum slows up its speed somewhat.† In a boiler so designed the tubes exposed to furnace temperature will become coated only by a thin scale resulting from that portion of impurities which will not precipitate or separate out except as a residue when the water evaporates. Owing to the small quantity of such material this deposit will form but slowly, hence the boiler can be operated for a considerable time without danger of burning.

122. But to apply this method to boilers of the header and water leg types is impossible. In these, between the point where the feed comes in and the water enters the lower tubes exposed to the highest temperature, this water must travel through nipples, headers, or water legs, at a velocity always very high as shown in Fig. 34, hence the precipitates are not permitted to settle quietly into a mud drum placed at the bottom of such headers or water legs, but are swept onward and into the tube as shown. Even if these keep in motion while the boiler is steaming, they may cause trouble after a shut-down. "Mud and sediment which may be prevented by the rapidity of circulation from settling on the heating surfaces while the boiler is working, are liable to settle in the tubes and headers when the fire is low or extinguished, and become baked on their surfaces when the fire is bright, or relighted."—Hutton, *Steam Boiler Construction,* page 315.

123. It is also shown in Sect. 231 that entering the feed as illustrated in Fig. 65 is not in accordance with the law of maximum fuel econ-

*There is one permissible exception to this rule. If by means of an economizer or other device the feed water is delivered into the boiler at very near the temperature of boiling then the purification of the water due to temperature and pressure will be accomplished outside of the boiler. In such case the water speed from feed entrance to where steam generating begins need not be kept low in order to permit precipitates to form and drop out, hence the area through the down-comer tubes may be reduced to any extent short of causing throttling such as occurs in header and nipple designs. If the area through the down-comers is equal to approximately one-half of that through the steam generating tubes such proportion will be ample.

†For a conclusive proof of the necessity of a mud drum of ample volume see *Tube Trouble from Dirty Feed Water* in *Power,* November 22, 1921. "The bottom of the rear water leg had an accumulation of this fine sediment all the way across the leg, up to and covering one-half of the bottom row of tubes. The ends of the tube at the rear legs were half filled with this sediment." Ample mud drum volume would have prevented this stoppage. This case also proves that the water speed through the tubes was very slow, otherwise the sediment would have been swept along and out of the tube, per Sect. 119.

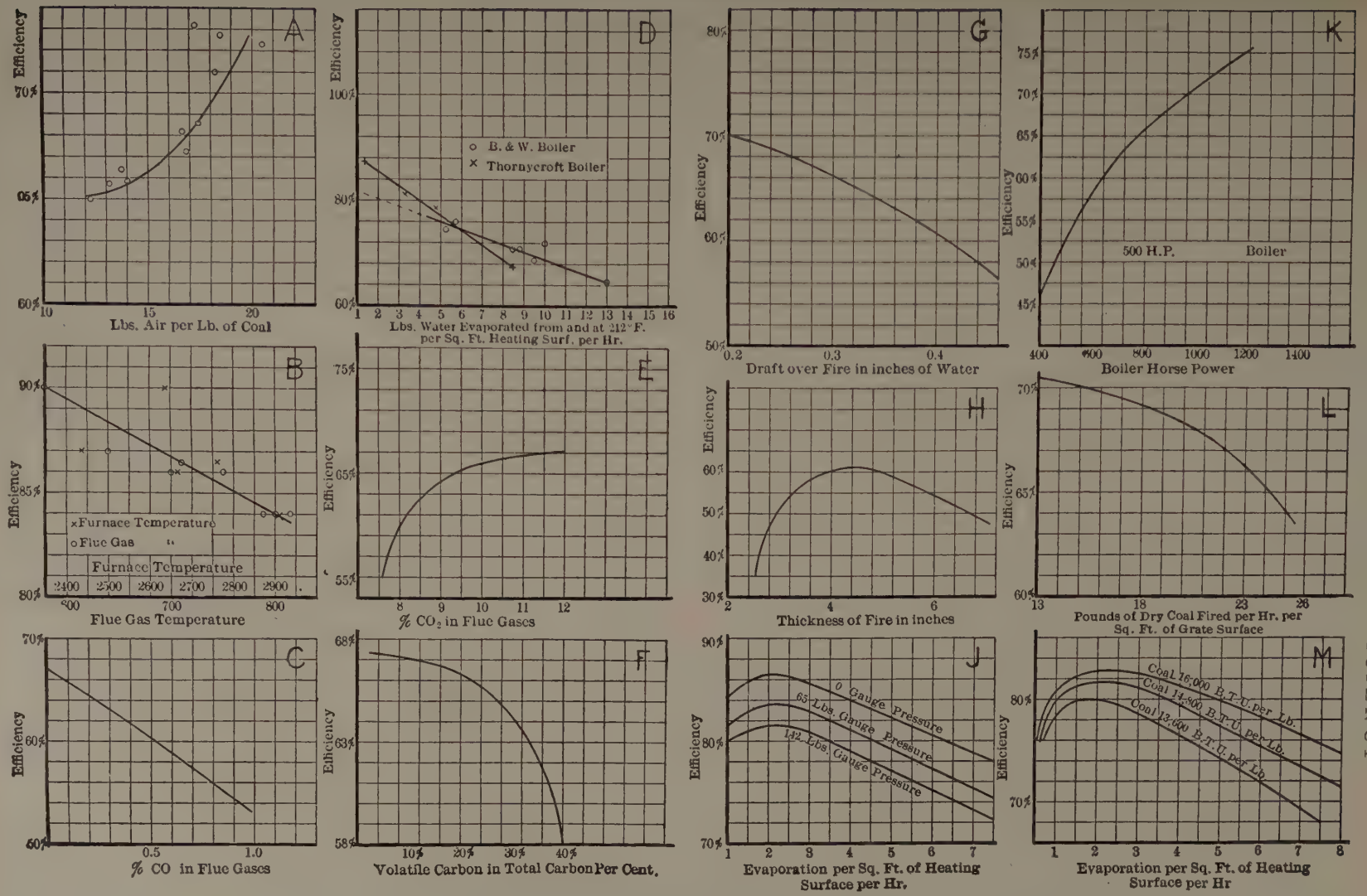


FIG. 47. GRAPHICAL ILLUSTRATION OF THE EFFECT OF VARIOUS FACTORS ON FUEL EFFICIENCY

From Prof. Lucke's *Engineering Thermodynamics*, pp. 809 and 810.

omy as stated in Sect. 132, but it is the only method available in a design of that kind.

124. From the start our thesis has been that rapid circulation is essential to high capacity, economy and durability in a boiler, but we now complete that statement by adding that this high velocity must be had at the part of the water circuit *where it is wanted,* namely from the point where the generation of steam begins to the point where that steam is disengaged, but not elsewhere as inevitable in all header types.

125. Next to making certain that the maximum possible water speed through those parts of the boiler subject to the highest temperature is obtained beyond any question, there is no other point of greater importance to the boiler purchaser than to satisfy himself that the design is such that precipitates will not be swept into the tubes over the fire, and by so doing he is insuring himself against tube losses, shut-downs, and possibly fatal accidents. See Sect. 123.

126. The above exposition disposes of the claim so often urged, that if a boiler gives good results when it is *clean* it will of course give *proportionately* good results when it is *dirty* inside and out. This could be true only if those parts of the heating surface similarly situated in each boiler would accumulate incrustation *at identical rates,* which, as above shown, is not true. Therefore the average condition of the surfaces between cleaning periods will vary, and the fuel efficiency will vary likewise. See Sect. 110 and Fig. 46.

Consequently, apart from scientific interest, *the only fuel efficiency results which give the boiler owner a true measure of what he is getting for his money are those obtained by making tests with equal care on a boiler when thoroughly cleaned, and again at the end of the run just before cleaning is due again, and taking the average of these two results!* For example, we have seen cases where there was 30% to 40% difference between these two results, hence the futility of being guided by one result only, *and that the higher one,* is apparent, and when this is realized there will be some quick and drastic changes made in the procedure of selecting boilers and of operating them when installed.

127. Fig. 47 shows the influence of just a few factors effecting fuel efficiency and illustrates how mere statements of results without ample information as to all factors involved are really of no significance. There are many more as will later appear. The absurdity of judging a boiler solely from its fuel efficiency without considering other items will become apparent by noting that if a boiler received its feed from an economizer and at a temperature of 250 deg. or even higher, *the fuel efficiency of the boiler alone could be materially increased by cutting out the economizer and feeding the boiler with cold water,* and the colder this water the higher the boiler efficiency would show up! Therefore, one easy way to get higher *fuel efficiency in boilers* is to discard *all* feed heating devices!

Thus again it becomes clear that all talk of efficiency is futile unless it refers to either *plant efficiency,* or efficiency of Capital, both of which would be greatly reduced by discarding feed heating devices.

128. Rankine's Law as to Fuel Efficiency. As above indicated, the feed water should enter the circuit at the proper point, which fact is seldom realized or acted upon. Before that point can be determined it is necessary to clear away some current errors as to the proper relation of the gas and water flow.

129. Prof. W. J. M. Rankine, an eminent English authority whose statements are seldom questioned, says in his *The Steam Engine,* 17th Edition, p. 262:—"In a steam boiler it is favorable to economy of fuel that the motion of the water and steam should on the whole be opposite to that of the flame and hot gas from the furnace. The coolest, that is, the *lowest* portions of the water in the boiler, should, if practicable and convenient, be contiguous to the coolest part of the furnace and heating surface; and if there is apparatus for *superheating* the steam, that apparatus will be most efficient if placed in the hottest part of the furnace."

130. This seems to have been accepted from decades without question, and by literally following it some fantastic designs have resulted, but none have succeeded. See example in Sect. 333. The reason is that the law as laid down is partly in error as to fact, and the suggestion as to superheater location, while correct as to fuel efficiency, is contrary to efficiency of Capital, and in such cases the latter must always prevail.

131. Thus, if a superheater be placed in the hottest part of a furnace and its tubes be directly exposed to such temperatures as are developed today by oil or stoker fires, it might, *while it lasted,* produce a fuel saving expressed by some fraction too insignificant to be worth while, but it would so quickly burn out that the scheme is

impracticable. In cases where superheaters are necessarily located in furnaces, care is taken to shield them from the full effect of the radiant heat, and to place them so that gas of highest temperature does not strike them. The recent introduction of radiant heat superheaters placed in furnace walls has confirmed the above statement.

The assumption that the water and gas must flow in opposite directions in order that the temperature difference between them should be a maximum, is not correct. It overlooks the fact that the boiling point of water increases with the depth, as proved in Sects. 53, etc., and this alters the entire case. In accordance therewith we amend Rankine's statement as follows:—

132. Rankine's Law Correctly Restated. "In a steam boiler, to secure the maximum fuel economy the feed should enter at the point where the coolest gases pass out, and the travel of the gases should be so directed that between the point where the feed enters and the point where the water stream is brought up to boiling temperature, the gas and water flow should be in *opposite directions;* from the point where generation of steam begins, to the point where the steam is disengaged, the steam, water, and gas should travel in the *same direction,* namely, upward. As the steam and water are both rising, the gas will be rising also, and all three of these media will be passing from a region of higher to a region of lower temperature." The effect of this is that the fewer the downward passes of the gas while steam is being generated, the higher the fuel efficiency of the boiler.

133. Where the Feed Should Enter. To enable the precipitates to separate out and deposit before the water reaches the tubes over the fire as specified in Sects. 121 and 122, it is preferable that the water flow in a descending current; thus the fall of the precipitates is not interfered with by the water. As the water flows along from the feed entrance to the point where steam generation begins, its temperature is increasing, hence the gas must flow in the opposite direction as above shown. In other words, *the feed should enter near the water line, and proceed at once to flow into a down-comer at the bottom of which, and forming part of the water circuit, is a mud drum of sufficient size to slow up the water speed enough to cause the precipitates to drop out of the circuit before the water passes into the tubes over the fire; the water speed in the down-comer should be less than in the up-comer, and the water should reach the lowest point in its circuit before the generation of steam begins.*

To cause the precipitates to drop into the settling space below with utmost efficiency the down-comer tubes should very nearly approximate the vertical so that the solids will not be deposited on the tube, a requirement impossible of attainment in horizontal boiler designs. Further, the water in the down-comer *must not be stagnant,* but move with sufficient speed to transport the sediments to the settling chamber below. See Sect. 529.

Few boilers comply closely with these requirements, but the Kidwell boiler does so to the letter, as shown in Sects. 528 to 530.

134. Feeding Into the Mud Drum. Through necessity this is resorted to by designs like Figs. 92, 101, 121, 142, and others, but it is an evil and often dangerous practice which should be avoided for reasons now to be shown.

135. Absorption of Gas by Water. Practically all natural waters contain air and CO_2 gas which cause corrosion and pitting. "Water is capable of dissolving about 8 cubic centimeters of oxygen per liter, (i. e., 8 parts in 1000), and appreciably more carbon dioxide. These two gases are the agents especially responsible for corrosive attack, and while some few scientists maintain that one gas alone is responsible, to the exclusion of the other, it is probable that both gases under certain conditions are active agents and mutually aid each other in metal wastage."—*Combustion,* Oct. 1921, p. 194.

The quantity of air and gas absorbed may be much greater than above stated, under certain conditions not unusual. "The amount of air dissolved in water varies with the temperature. In the winter time it is approximately 5% by volume. At each temperature there is a definite saturation point, that is to say a maximum amount which the water can hold in solution. Thus at summer temperature the amount is about 2½ cu. ft. in every 100 cu. ft. At boiling point the amount which can be held in solution is zero."—*Combustion,* Oct. 1921, p. 166.

The last statement is not exactly true. Stromeyer, a most reliable English authority, treats this subject quite fully on pp. 72 to 78 of his *Marine Boiler Management and Construction,* which should be consulted. He says:—"It was formerly believed that *all* air could be expelled by boiling, and that at a given temperature a fluid absorbs a given volume of gas quite inde-

pendent of the pressure; more recent experiments show that apparently neither view is quite correct. The weight of absorbed gas is therefore proportional to the gas pressure. In Table 4 the volumes absorbed at various temperatures are given, and also the weight of absorbed gas if the pressure is one atmosphere. When a mixture of several gases presses on a fluid, the effective pressure of one of these gases is the product of the combined pressure into the volumetric proportion of the gas. Thus for air, where the volumetric percentages of oxygen and nitrogen are as 20.8 to 79.2, oxygen only exerts a pressure of 0.208 atmosphere, and nitrogen 0.792 atmosphere, and the weight of oxygen absorbed by water when in contact with air is only 0.208 of what it would be if pure oxygen were in contact with the water. Air and steam behave in the same way."

TABLE 4.

AMOUNT OF GAS ABSORBED BY WATER.

Name of Gas		Amount of Gas absorbed by 1,000 c.c. Water under a Pressure of one Atmosphere							
		Oxygen		Nitrogen		Carbonic Acid		Carbon Monoxide	
Temperatures		Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight
°C.	°F.	c.c.	per 1,000	c.c.	per 1,000	c.c.	per 1,000	c.c.	per 1,000
0	32	48·9	0·070	23·5	0·029	1713	3·38	35·4	0·044
20	68	33·3	0·044	16·5	0·019	942	1·73	24·9	0·028
25	77	31·0	0·040	15·6	0·018	830	1·49	23·4	0·026
30	86	29·0	0·037	14·9	0·017	738	1·31	22·1	0·025
40	122	26·4	0·033	13·6	0·015	607	1·04	20·4	0·022
60	150	23·8	0·028	12·5	0·013	438	0·71	18·2	0·018
100	212	23·2	0·024	12·9	0·012	...	...	19·2	0·017

Note.—The above are a summary from various experiments by Bunsen, also A. Winkler, 'Zeitschr. f. phys. Chemie,' 1892, vol. ix. p. 171; and Bohn and Bock, 'Wied. Ann.,' 1891, vol. xlviii. p. 319. The volumes in this table are for the respective temperatures.

136. Under the influence of the temperature existing in a boiler these gases separate from the water, pass off with the steam, and finally appear in the condenser as "uncondensable gases." When the boiler feed enters near the water surface such gases pass directly off, hence sweep but little of the boiler surface. But, if the feed enters the bottom of the boiler the gases then travel up the heating surface for the entire distance to the top, and produce corrosion and pitting all along their path. Also, as the water in the mud drum is more nearly quiescent than elsewhere, this affords an excellent opportunity for these gases to produce their evil effects. "Where it (i. e., pitting or corrosion) is directly chargeable to dissolved gases the action is more or less selective, in that *the area of greatest virulence is confined to parts where the circulation is sluggish, and entirely to the water space.*"—J. R. McDermet, *The Interpretation of Boiler Water Analyses,* A. S. M. E. Transactions, 1921. An idea of the magnitude of these evil effects may be formed from Stromeyer's statement following:—"If the feed be allowed to fall to the bottom of the boiler, it will be heated gradually under conditions which prevent the escape of the absorbed air which is retained until the mixture comes into contact with a heating surface. Then while steam is being generated, which escapes, the liberated oxygen attaches itself to the plate and attacks it. If the feed amounts to one ton per hour it will, under the above conditions, contain enough oxygen to corrode 4 ozs. of

iron or say 6 lbs. of iron per day. * * * Carbonic acid will attack iron, forming a ferrous salt which is an active absorber of oxygen, and changes itself into a simple oxide to which the liberated CO_2 is attached mechanically and ready to attack the adjoining iron."

In consequence of the above stated facts engineers are rapidly realizing the necessity of deaerating feed water, concerning which see Sect. 214.

137. Further, in a water tube boiler fed through the mud drum the entering water passes directly into the tubes over the fire before undergoing purification as described in Sects. 121 and 122, hence the percentage of tube losses is greatly increased, as is also the danger of causing leaky tubes due to cold water coming into contact with the drum sheets exposed to furnace temperature, as in Figs. 92, 141, 142, etc. And finally this method is directly contrary to the law of fuel economy as stated in Sect. 132. Accordingly, Stromeyer thus sums up the matter:—"*No plan could be worse than to discharge the feed at the bottom of a boiler.*" See also *Boiler Drum Pitted,* in *Power,* Oct. 25, 1920, and *Corrosion of Boilers and Economizers,* in *Mechanical Engineering,* Sept., 1921.

138. The Feed Pipe Outlet must be so arranged that the entering water is distributed throughout the stream traveling in the water circuit of the boiler, for two reasons:—(a) To prevent concentration in certain parts of the boiler, as illustrated in Sect. 231; (b) To prevent temperature differences between tubes sufficient to cause trouble with the tube joints. Thus, when boilers are fed into the bottom as in Figs. 92, 101, 121, and 142, or elsewhere through only one or two pipe openings, the feed stream, without being broken up or properly mixed with the boiler water, may pass directly into several tubes and so reduce their temperature that the sudden contraction resulting from this practise will cause the tubes to leak or even pull out of the tube holes. Trouble from this cause is more frequent than usually suspected, but the true cause above explained is seldom realized either by operators or designers.

139. Efficiency of Capital. This subject alone would require a volume for its proper presentation, hence we can touch upon only a few vital points. It involves fuel efficiency; steadiness of water level; first cost; cost of installation; cost of space occupied, buildings and all auxiliary apparatus; simplicity of design; liability of derangement of parts; relative frequency of tube renewals; relative cost of and time required for tube renewals and other repairs; safety, ability to stand heavy and protracted overloads with good fuel efficiency and no reduction in safety; accessibility of parts; relative frequency and cost of cleaning; quality of steam produced, i. e.—whether wet, or dry and superheated; and many other factors. As illustrating the necessity of considering all of these, the following is pertinent.

140. Besides the boiler itself, the buyer must provide grates or stokers, setting, feed equipment, forced draft apparatus (if such is used), breeching, stack, building to house the plant, and the ground upon which all these are to be located. *Every one of these costs more for an inferior boiler than for a good one,* because a wasteful boiler, to deliver the same output as a good one, requires a larger capacity of stoker, coal bins, forced draft apparatus, breeching and stack, hence the apparent saving made by purchasing a "cheap" boiler will be more than absorbed before the boiler is ready to produce a pound of steam. A chain is useless for any particular purpose if it is short just one link, and since in this chain of equipment the boiler is the one piece of productive apparatus, failure of its means failure of all. "The *best* is always the *cheapest* in the long run." Note Mr. Azbe's summation of this matter at end of Sect. 593.

Of the various points above included under Efficiency of Capital we have here space to discuss but three, and those only very briefly.

141. Relative Time and Expense of Cleaning Header and Curved Tube Types. Formerly, makers of header types energetically urged that their designs require less time and labor for cleaning than necessary for curved tube boilers, but such claims are seldom heard now since such makers found that to keep up with the demand they, too, had to take up the manufacture of boilers having curved tubes. The absurdity of their claim is likewise exposed by the action of the U. S. Navy in adopting the curved tube boiler exclusively. But, that those who have any doubts on the subject may be further informed the following information is given.

142. Every tube, straight or curved, is cleaned by a hydraulic or air-operated turbine which drives the cleaner and this does the work with equal speed and efficiency whether a tube be straight or curved. Therefore, the actual clean-

ing of the tubes, for an equal footage in length, will require the same time in either type. The difference comes in opening up the boiler for cleaning, and then closing it. As to curved tube boilers a Kidwell boiler can be got ready for cleaning by opening four manholes, which can be done in 30 to 40 minutes, and they can be closed in about the same time. A header type, according to size, will require 2 to 4 days for the same work, and the expense will be in proportion. It must be remembered here that horizontal tube boilers pull the impurities into the tubes over the furnace to far greater degree than the Kidwell boiler (see Sects. 120 to 122), hence bake to a hardness which makes their removal much more difficult and slow than if deposited in the rear where the tubes are swept by gas of lower temperature. Actual example:—By referring to *Tests of Stirling and B. & W. Boilers*, p. 63, it will be seen that by actual record the cost of cleaning a boiler like Fig. 30 as compared to one like Fig. 102 was 35 to 6, or practically 6 times, which disposes of the matter completely. As confirming this, it is common to open up, clean and close a curved tube boiler and get it ready for steaming in 24 hours. Reference to *Mechanical Engineering*, Sept. 1921, p. 588 will disclose some records of the time necessary for cleaning straight tube boilers, and the comparison of the two cases is illuminating. As corroborative evidence, however, it may be noted that in the South West, where the average feed water is bad, the header type of boiler has steadily fallen out of the race.

143. Upon inquiry it will be found that the labor of removing and replacing caps is so great (See Sects. 145 and 146) that operatives frequently shirk the work, and clean only the two or three rows of tubes at the bottom except at long intervals. The upper tubes, of course, lose in efficiency by this practise, but as they do not burn easily this is not seen, but it *affects the coal pile none the less!* Some makers even suggest this practise. See catalog of Foster Marine Boilers, p. 52, right hand last paragraph, Weaver's statement in Sect. 251, *Mechanical Engineering* where above cited, and end of Sect. 150. Finally read carefully Sects. 550 to 552.*

144. Entirely disinterested evidence as to the difficulty of cleaning header types of boilers is given in an article by Mr. A. C. McHugh, and another by Mr. Warren D. Lewis, both of which are reprinted below. The first of these is from *Power*, Jan. 16, 1917, and the second is from the same journal, Sept. 9, 1919. It will be noted that none of the precautions, difficulties, and deficiencies so well set forth by these authorities apply to the Kidwell boiler.

CARE OF WATER TUBE BOILERS

By A. C. McHugh

145. "In many small plants where water tube boilers are installed, the drums are scaled and the tubes turbined regularly and the loose mud and scale taken from the mud drum, but that is about as far as the cleaning generally goes. *In boilers of the Heine type the water legs should be given the same attention as the tubes or drum.* The front leg may be scaled while the caps are off for the tube cleaning, but the back caps should also be removed at least every second or third cleaning to permit a thorough scaling of this portion, *as it is surprising how fast the scale will collect there. What is true of the Heine is even of greater importance in the B. & W. type and as it is a disagreeable task, the headers and vertical circulating tubes and nipples are often slighted.* But the engineer should always make it a point to see that these parts are free and reasonably clean before the boiler is closed up.

"From a safety point of view, the rear vertical circulating tubes and headers are perhaps the most important portion to keep clean, for the circulating tubes are of the same size as the

*To obtain reliable and first-hand information on this we requested a prominent engineer who has built and operated numerous large plants, to state the facts as to one of the leading plants in a large industrial center, using sinuous header boilers fed with much better water than usually available. His reply follows:—"As you know, they will probably clean a boiler completely from top to bottom once a year; then probably once a month they will clean from two to four rows of the lower tubes in the boiler. The amount of time used in doing this work depends a great deal on how hard the scale is in the tubes. We generally allow 6 days time for 2 men to clean a 500 HP. boiler completely, that is *taking off only the front caps and boring out the tubes.* When it comes to replacing the caps we would use 3 men; one man would be washing the caps in a bucket of coal oil, another man putting them into place, and one man tightening them up. I think they could put all of these caps on in one day's time. When we clean only 3 or 4 rows of tubes we generally allow 2 days for 2 men. Of course if we were in a hurry for the boiler we would try putting on additional men to do this amount of work in one day." Note, however, what is said in Sect. 145 as to danger of rear headers being packed with scale if the rear caps are not also removed.

nine or more heating tubes which they supply, the rate of circulation is rapid and they should have as clear a passage as possible. *In fact, many tube failures have been caused by an insufficient supply of water being furnished to the lower tubes during a period of heavy overload, as the greater portion was by-passed through the upper tubes thus leaving the lower ones partly dry.* To prevent this, attempts have been made to bush the front ends of the upper tubes, *retarding the circulation through them and sending a larger supply to the lower ones.* See Figs. 80 to 83.

"In cleaning the rear circulating tubes, a scraper having a jointed handle is sometimes used; but better results will be obtained through the use of a water turbine cleaner. While it is not impossible to use a steam cleaner for this work, it must be done through the manhole in much the same manner as in the Stirling boilers, while with the use of a water-operated cleaner a man may safely work from inside the drum.

"To clean the headers, the caps must be removed and a scraper or bar used through the handholes. *About the hardest part to clean, in this type of boiler, is the mud drum nipples.* Although not as important as the circulating tubes, they should be kept reasonably clean.

"A boiler that has been cleaned, but has not had the caps removed from the rear headers, should never be closed up until a lamp has been passed from the upper end of each circulating tube, through the tube, header and mud drum nipple, to make sure that they are all clear. *In doing this, the writer has often found the headers completely packed with loose scale.* Should the boiler be fired up without removing this scale, tube failures would result.

"All who have had occasion to test the B. & W. type know that the *mud drum nipples are about as susceptible to leaks as any other point,* (See Sect. 240), *and it often happens that it is almost impossible to see the nipple because of the deposit of scale that has leaked from them and been allowed to accumulate.* This should not be permitted, as the nipples are in a position where soot deposits heavily and forms one of the most destructive corrosive agents when wet. As a result, the deterioration of these nipples is nearly always from the outside. If the exterior of these nipples is thoroughly cleaned and painted with a good heat-resisting boiler paint, it will be easy to detect defective nipples at the next regular cleaning period.

"If it is possible to dent a nipple by lightly tapping a blunt-nosed tool held against its side, a new one should be put in. *These are more difficult to remove and replace than any other nipple or tube in the B. & W. type of boiler and require the exercise of judgment and care.*

"In preparing to replace a nipple, first make the following calculation as to the end pull on it; Multiply the boiler pressure by the area of the nipple, then add its share of the weight of the mud drum and water=the total weight divided by the number of nipples. For example: Boiler pressure, 100 lb.; nipples 4 in., equals 12.56 sq. in.; 12.56×100=1,256. Adding 35 to 50 lb. for the weight per nipple of the mud drum and water gives about 1,300 lb. to be supported by each nipple. Won't that promote carefulness?"

NEGLECTED PARTS OF WATER TUBE BOILERS

By Warren D. Lewis

146. "Perhaps the most neglected parts of water tube boilers are the front and rear headers with their respective handhole fittings.

"*It is usually a hot, dirty job to clean headers and caps,* and as for closing up the boiler, this is usually done as quickly as possible, the front and rear doors shut, and the whole thing forgotten until possibly a cap gasket blows out or the regular overhauling and cleaning time arrives. (See Sect. 143). When the doors are opened, everything is usually covered with a white scale which is hard to remove.

"Now, this condition makes extra work, which is unnecessary. The time to begin to prevent it is when the boiler is new. Headers are sometimes painted by the boiler manufacturer to prevent rusting, but usually not even this precaution is taken. (See Sects. 241 and 242). If at this time the headers were rubbed down with plain flake graphite mixed with a little water as a carrier, and the tube holes, caps and dogs treated the same way, any deposit from a leaky cap could be easily removed with a stiff wire brush.

"When closing up the headers it should not be attempted to pull the caps up to their final position. While the boiler is filling with water, leaks should be looked for and corrected even if it is found necessary to empty the boiler again. As the temperature rises the caps should be gone over and tightened, and again when the boiler goes into service, under full steam pres-

sure. *If the caps are watched for a day or two for leaks,* the doors may then be closed with the assurance that there will be no dirty looking headers a few weeks or months later. Of course it is possible that with an old boiler the preceding method is not the whole solution of the problem, but leaks from caps are usually due to carelessness.

"Most boilers are now equipped with inside caps, and here the pressure assists in making the cap tight. To clean the bearing or joint surface of an outside cap is a simple operation, especially with the aid of a resurfacing machine; but cleaning the header for inside caps is an awkward, tiresome job. *A poorly cleaned header will usually cause the caps to leak.* One way to prevent this is to inspect the header by means of a small mirror held inside, light being supplied by an electric lamp. This will show any dirt on the header and is much more satisfactory than passing the fingers over the surface. For round inside caps there is a simple, inexpensive machine made which will scrape the surface inside the header better and quicker than can be done by hand. I have never heard of a machine to scrape the surfaces of elliptical holes.

"The selection and use of handhole gaskets is an important part of this work. There are several kinds, the most common ones being either of asbestos rubber or semi-metallic, these last being composed usually of a thin copper or soft-steel ring with an asbestos core. I prefer the semi-metallic gasket as it usually makes less work in cleaning headers and caps when removed. If the asbestos or rubber gaskets are rubbed well with graphite, they are not likely to bake on the metal and cause trouble when removed. Notwithstanding the small additional cost of the semi-metallic gasket, the labor saved makes it, I believe, the cheapest in the long run."

As to what Mr. Lewis says about tightening leaky caps when under steam pressure, a writer in *Power,* January 20, 1920, warns that such procedure is a menace to life, and that the only safe way to handle such cases is to *open and clean the joint.* This is certainly true, and it does not serve as a good recommendation for any boiler so constructed as to require such procedure.

Walter N. Flanagan published an article in Journal of *Ass'n. of Iron and Steel Elect. Eng'rs* July, 1922, from which the following is taken:—"The rapidity of cleaning is quite a factor in most plants as it determines the number of spare boilers required, since other repairs except in unusual cases can all be made within the time required for cleaning. * * * With a 1000 H.P. straight tube boiler merely a washout requires the removal of at least 500* tube caps in addition to the opening of the header doors or the removal of steel casing sections, in case the boiler is provided against air infiltration. Scale in headers and nipples is more difficult of removal than from tubes and drums. * * * The bent tube boiler can be opened up and cleaned in practically the time spent in merely removing and replacing handhole caps on a straight tube boiler. This is due to the fact that on the largest bent tube boiler only 8 manhole plates have to be unbolted and swung back and an air connection slipped into place connecting the mud drum manholes with doors in the setting. This connection causes air to be drawn from the upper drums in which the men have to work, downward into the mud drum, thus keeping the upper drums cool. * * * A bent tube boiler can be completely washed out in the time required for the two lower rows of tubes in a straight tube boiler * * * In starting up a large bent tube boiler there are more than 1,000 less chances of leakage due to the elimination of handhole caps."

In the discussion of Flanagan's paper, J. H. Davis, Foreman Steam Dept., Carnegie Steel Co., Youngstown, O. said:—"I have had charge of good and bad designs of both kinds of boilers for about 25 years, both doing the same kind of work and mainly with untreated water. I have found that the good bent tube boilers are less troublesome to operate and maintain than the good designs of straight tube, and that the badly designed bent tube were also easier to mantain than the badly designed straight tube boilers."

147. Relative Frequency of Tube Renewals. As most renewals are required because of failures due to overheating of tubes, it is clear that they will be most frequent in those types deficient as to rapid circulation and place of deposit of solids. But as shown in Sects. 73, 74

*This should, if the work is properly done, read 1000 instead of 500. See Sect. 551.

and 120 to 122, such deficiency is inherent in all header designs, therefore they lose tubes more frequently than done by other types. Such is proved by actual reliable statistics. In *Tests of Stirling and B. & W. Boilers,* pp. 56, 61 and 69 it is shown that on basis of equal work done in the same plant with all other conditions identical, the tube renewals in regular service for a forged steel header type as compared with a curved tube boiler were [illegible]t 61 to 1. Observations in another adjoining plant operated by the same Company were that the losses of a prominent water leg type as contrasted with the curved tube type were 40 to 1. And, since the Kidwell boiler has even more rapid circulation than the curved tube design which was used for comparison in this case, the proportion will of course be still greater.

appearance. They might be caused by a slight reduction in the thickness of the plate, the flaking off of a piece of scale and a small flaw, but these special places always existed. On the left, at the top of Fig. 48, a bubble was beginning to rise off the previously wet plate. Any magnesium chloride that might be evaporated out of the water in the formation of the bubble would be deposited on the plate and would be dried out under the protection of the bubble. Finally, the bubble would escape, as shown, (at the right end of Fig. 48), and the plate would be wetted again. During the time that the chloride was dry it would, at the temperature of boiling water, produce hydrochloric acid which would 'bite' into the plate. The action then proceeded as shown in Fig. 49. A little crater was formed, surrounded by a heap

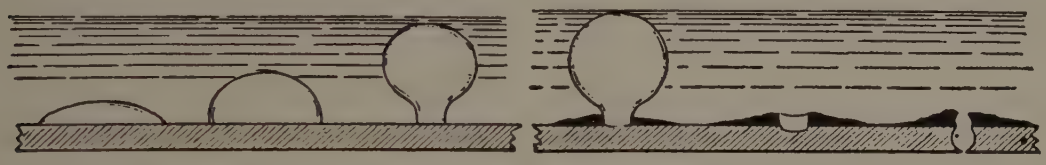


FIG. 48 DEWRANCE'S EXPERIMENTS FIG. 49

148. It is interesting to note here two causes of tube failures which particularly affect all headers or other restricted circulation types of boilers.

149. How Magnesium Chloride Destroys Steam Locked Tubes; Dewrance's Experiments. "Developed acidity within a boiler is perhaps the most common type of corrosion met with in power plant practise and magnesium chloride is frequently the responsible agent."—*Combustion,* Oct. 1921, p. 163. On this point, however, there has been considerable controversy, some maintaining that magnesium chloride does not affect the steel. The reason for this diversity of opinion has been cleared up by the experiments of Sir John Dewrance, for which see *Corrosion in Boilers,* in *Power,* March 29, 1921, from which the following is taken:

"The corrosion of the boiler heating surfaces was caused by dry magnesium chloride, but the problem was, How could the chloride become dry below the water level? In his explanation of this phenomenon the lecturer used the diagram shown in Figs. 48 and 49. There were always peculiar spots in boiler plates which steam bubbles preferred as the site of their of oxide, which was thrown out by the explosion of the bubbles, and finally developed, as indicated on the right, into a pocket with a narrow opening in which the acid was boiled. Ultimately the plate was eaten entirely through."

The article cited shows that chloride *in solution* did not attack steel, and that trouble occurred when the steam bubbles were in contact with the metal. This simply adds one more item to the long list of troubles due to steam pocketing in tubes. And to the same degree it adds another argument in favor of rapid water circulation in boilers.

150. Failure of Steam Locked Tubes Caused by Oxidation. In *Journal of South African Institution of Engineers,* April 1920, Mr. T. G. Otley reported a tube failure in a boiler of the type shown in Fig. 30, by which three operatives were scalded and one died. The tube opened out for a length of 10 inches, and the speaker advanced the following explanation of this case.

"The failure is of more than usual interest, in so far as it very clearly illustrates a theory which I have held for some considerable time. * * * The bottom row tubes in water tube

boilers are worked very hard, but under normal working they come to no harm because the water is in contact with the inside surface of the tube and the metal cannot be overheated. * * * Assume, as is reasonable under certain conditions of working, that steam bubbles attach themselves to the wall of the tube, then the temperature gradient is altered, and while remaining the same on the furnace side the temperature may easily rise to 700° or 800° C. (1292° to 1472° Fah.) on the steam side, under which condition dissociation of the steam will occur and the metal on the steam side will become oxidized, forming thin layers of oxide. With the bursting of the steam bubble, water, at approximately 200° C. (392° Fah.) temperature, comes in contact with the tube, which contracts and the oxide cracks away. One can imagine this process being repeated until the sound metal is reduced very much in thickness until, finally, it is unable to resist the pressure combined with the temperature, and it then opens out and bursts. If careful measurements are made of the burst tube it will be found that it has stretched very little, but the thickness of the tube nearest the fire, where it has burst, comes down almost to a knife edge. On the other piece of tube adjoining the burst an incipient blister is forming, and it will be observed that the iron oxide on the steam side, which I have referred to, is clearly in evidence. It is also clear that some of it must have cracked off and been swept away by the rush of steam and water. * * * The trouble cannot be accounted for by the quality of the material, which is excellent in every respect. The moral to be drawn is that when boilers are to be worked very hard it is of the first importance that the feed water should be of excellent quality, and that the lower tubes should be cleaned at fairly frequent intervals to prevent anything but the slightest scale adhering to them."

151. The latter remarks confirm Weaver's statement in Sect. 251. Mr. Otley's explanation is ingenious, but perhaps further confirmation should be awaited before its correctness is accepted as proved. In any event, this case once more proves the inevitable danger of steam-locked tubes in header boilers.

152. Relative Time and Expense of Tube Renewals. As to this item also the finding is all in favor of the curved tube types. Here an important fact is almost invariably overlooked. While it costs some money to replace boiler tubes, *it costs far more to have a boiler out of service while tubes are being replaced!* From the relative frequency of tube renewals it is clear that the facts are overwhelmingly in favor of curved tube designs. Yet even when the latter require an occasional tube renewal it may usually be made easier and quicker than in the header types, because the curved tubes can be replaced *without pulling them through the tube sheet,* as must be done in the header types. In the latter the tube is always caked outside with deposit and usually swedged and enlarged by the cleaner sufficiently to prevent it being pulled through the tube hole unless it is split and collapsed inch by inch, which is a long, tedious job. Refer to *Steam,* p. 65, and note the vigor with which this writer proves that removal of tubes in a fire tube boiler is a "serious undertaking" because it is difficult, if not impossible, to pull the tubes through the tube sheet, overlooking the fact that *precisely the same difficulty exists when removing tubes from his own and every other header type of boiler,* thus illustrating the Scriptural simile of the mote and the beam.

Mr. W. N. Flanagan, as cited in Sect. 146, says—"However, the tubes which are to be removed are naturally seldom in good condition. Usually they are warped, bagged, blistered or split, which renders them larger than the holes in the tube sheet. Therefore the removal of an old tube from the middle rows (of a straight tube boiler) is generally a tedious, laborious job requiring chain blocks, jacks, etc., and *always risking the damaging of the tube hole!*

"Any tube may be removed from a modern bent tube boiler by merely cutting out the ends and either dropping between the rows of tubes into the combustion chamber or spaces between banks and removing through the ash gates or setting doors. The new tube is replaced through the same path. No matter how bagged or warped the tubes are, a new tube can be readily replaced unless the old tubes had warped sideways more than half an inch."

153. In *Power* for November 14, 1916, is printed the following letter.

"Removing Ruptured Boiler Tube."

"It is general practise, when a tube ruptures in a water tube boiler, *to cut out a sufficient number of tubes to enable workmen to get to the one that is defective,* as it is usually bagged so that it is not possible to pull it through the

header. This method is not only expensive, *but requires a great deal of time,* keeping the boiler out of service.

"A few weeks ago a tube ruptured in the eighth row from the bottom and near the center header in a (certain header type of) boiler. To cut this tube out it would have been necessary to *take out 15* more, and the boiler could not be kept out of service so long, so it was decided to pull the next tube, then use an oxyacetylene welding outfit to cut the bagged one in small enough pieces to be taken out through the header. The whole operation—taking out the two tubes and replacing them with new ones—*required but 12 hours for 2 men,* saving a lot of time and expense.

"Louisville, Ky. Joseph L. Brown."

If the above was considered so unusually good a performance that it was worth recording, the average case is of course worse. By "general practise" the author of this letter refers to *header type boilers only,* not to curved tube types like the Kidwell boiler.

154. Fact Versus Mere Assertion. Since some makers of straight tube boilers still urge that curved tubes are at a disadvantage as to replacements when a tube fails, the following is pertinent.

Some of the leading boiler builders of the world offer both types, and their records show that the curved tube designs in this particular are superior to the others. They often admit this without realizing it. Example:—See *Saving Coal in Steam Plants by Using Superheated Steam,* by Babcock & Wilcox., p. 11, and note the vigor with which this writer points out that the superheaters he is advocating are constructed of *bent tubes, in consequence of which construction troubles from expansion are completely eliminated.* If curved tubes are so efficient in obviating expansion troubles in *superheaters,* are they not equally so when used in *boilers?*

The U. S. Navy has gradually abandoned straight tube designs of boiler and taken up others having curved tubes, thereby destroying a leading argument of advocates of straight tubes.

155. In a matter like this the final verdict lies with those who have tried both types for a long time. The verdict from this source is emphatic. The use of curved tube boilers has increased with great rapidity for the last three decades, and today they are in the lead and will hold it for all time to come. Such boilers for this long time have been exported to Canada, Mexico, West Indies, Hawaiian Islands, Alaska, Philippine Islands, Japan, China, Tasmania, Europe, South Africa, etc., and the volume of such trade is rapidly increasing. If there were any difficulty as to a tube replacement such trade would not continue to grow. Argument is superfluous. See Sects. 241 and 242, and read *Bent Tube versus Straight Tube Boilers,* by W. N. Flanagan, *Ass'n. Iron & Steel Electrical Engineers,* July, 1922.

156. The Relation Between Furnace Volume, Height and Fuel Efficiency. Until recently the greatest loss in steam making was due to inefficient furnace performance, and that is largely the case today. There is, however, now no excuse for this except indifference and reluctance to put into daily use information now at the command of anyone who cares to avail himself of it. It is now fairly well understood that combustion is a complicated chemical process, and therefore requires constant vigilance as to keeping the conditions such as to produce the most efficient results. But to attain such results the furnace arrangement must be made right at the start. The important question then is, "What features are necessary in order that the furnace design may be right?" Valuable and precise information on this is given in Bulletin 135, U. S. Bureau of Mines, on *Combustion of Coal and Design of Furnaces.* The two essentials, apart from proper form of grate and sufficient draft to burn the necessary fuel are:—(a) The greatest possible distance from the fuel bed to the point where the gases strike the boiler surface, and (b) Ample effective furnace volume for completely mixing and igniting the air and volatile matter. As fuels vary as to the amount of volatile, larger and higher furnaces are needed for some than others. In general, however, the larger the furnace, within reason, the more perfect the combustion, the less the percentage of excess air needed, and the higher the efficiency.

157. Relation Between Furnace Volume, Air Supply, CO_2 and Fuel Efficiency. To prove the above statement we reprint pages 90 to 97 of Bulletin 135 practically verbatim except that the cuts are renumbered to suit their position in this book.

158. "The Most Economical Air Supply for a Given Furnace and Given Fuel. For a given furnace and a given fuel there is a certain percentage of excess air which gives the maximum over-all efficiency of a steam generating

apparatus. If the supply of air is increased beyond this percentage the over-all efficiency drops because of the heat lost in heating this extra air. If, on the other hand, the air supply is decreased below this best percentage, the heat losses increase on account of less complete combustion. These are the two principal causes of heat not being available for a boiler and the ones that are affected by air supply. The percentage of excess air giving the lowest sum of these two combined losses varies with the size of the combustion space and the kind of coal. When the combustion space is large, smaller air excess is necessary to obtain good combustion than when the combustion space is small. With coals having low percentages of volatile matter less excess air is needed for nearly complete combustion than with coals having high percentages of volatile matter. Figs. 50 to 54, inclusive, show that these statements are true. In Figs. 50 to 53 the abscissas are the percentages of air in excess of the amount theoretically needed to oxidize completely all carbon to CO_2 and all hydrogen to H_2O. The lower scale gives the corresponding percentages of CO_2 in the products of combustion. The ordinates are the percentages of heat not available for the boiler. The straight inclined line gives the quantity of heat that it takes to raise the temperature of the dry air, supplied for combustion, from atmospheric temperature to the temperature of saturated steam under 150-lbs. gauge pressure. The dotted curves in the lower part of the figure give the undeveloped heat in the gaseous combustible at the end of that part of the combustion space having a ratio to the grate area indicated by the figure at each curve. Thus, for example, the curve designated by *3* represents a furnace having 3 cu. ft. of combustion space to every sq. ft. of grate area, and so on. Each of the solid curves in the upper part of the figure gives the sum of the quantities of heat shown by the straight line and one of the dotted curves; that is, it shows the quantity of heat not available for the boiler due to both incomplete combustion and the sensible heat in the dry furnace gases. The heat in the moisture of the coal and that formed by the burning of hydrogen does not vary with the air supply and therefore does not affect the shape or the horizontal position of these curves. Similarly, the change in the boiler pressure does not change the slope of the straight line; it merely raises or lowers the line. Inasmuch as it is desired to show the minima in the upper curves, or in other words the percentage of excess air giving the least losses, and therefore the best results, the moisture and the steam pressure need not be taken into consideration in compiling such curves. That is, only those losses directly affected by the excess of air are considered here. These losses are expressed in percentage of the calorific value of coal.

"The upper curves of Figs. 50 to 53, inclusive, show that *as the size of the combustion space increases the minimum losses are obtained with a lower excess of air and a higher percentage of CO_2 in the furnace gases. The minimum losses in the furnace having a small combustion space are much larger than the minimum losses in the furnace equipped with a large combustion space.* However, with the large combustion space the minimum losses extend over a much smaller range of excess air than they would with a small combustion space. This means that with a furnace having a large combustion space more skill is required to keep its performance within the narrow range of minimum losses or maximum efficiency than to operate a small furnace at its best. With the furnace having a small combustion space a variation of 50 to 100% in the excess of air, and even more, makes very little difference in the performance of the furnace. However, *the maximum efficiency of the furnace having a large combustion space is so much higher than that of the furnace with a small combustion space that there is little doubt left as to which furnace is preferable.*

"Figs. 50, 51 and 52 were prepared from tests of the three different coals at the same rate of combustion—50 lbs. per sq. ft. of grate per hour. Comparison of the curves in the three figures shows that with the same size of combustion space considerably more air is needed for the best results when burning high-volatile coal, such as Illinois, than when using the low-volatile Pocahontas coal. Thus with a furnace having 5 cu. ft. of combustion space per sq. ft. of grate area the best results with the Illinois coal were obtained when the excess of air was about 70%, whereas with the Pocahontas coal the best results required only about 30% of excess air. However, this best performance with Illinois coal appears to be about 3% of the total heat in coal lower than the best results with the Pocahontas coal.

"To show the effect of the rate of combustion on the excess of air giving the best results

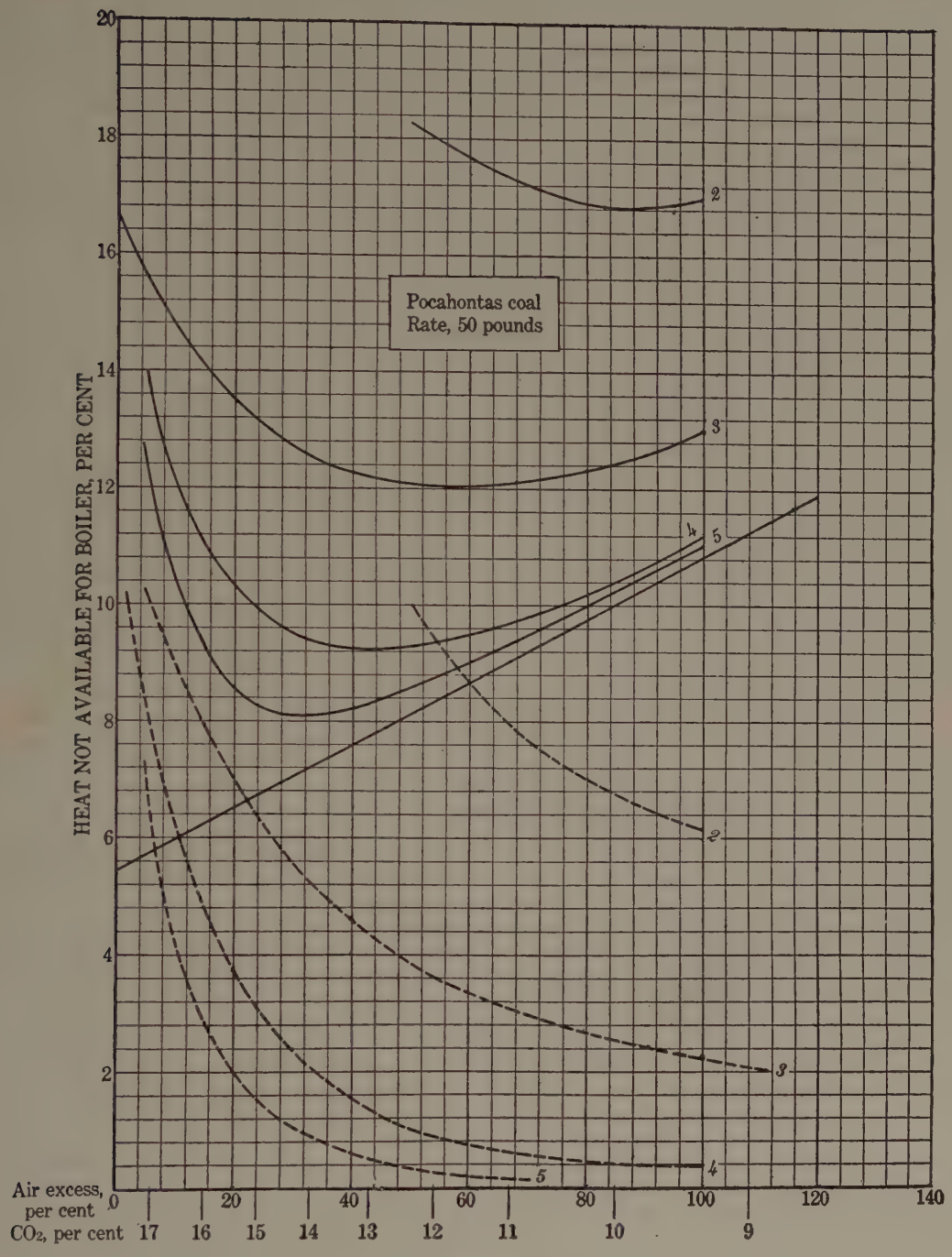


FIG. 50

Effect of air supply on the two principal sources of heat loss in a steam-generating apparatus as shown by tests of Pocahontas coal; rate of firing, 50 pounds. The straight inclined line indicates the increase in quantity of heat absorbed in heating the air supply from atmospheric temperature to the temperature of steam in the boiler. The dotted curves show percentage of heat not developed, owing to incomplete combustion, in a furnace having the ratio of combustion space to grate area indicated by the figure near each curve. The solid-line curves represent the sum of the heat losses shown by the straight line and each of the dotted curves, and show what the excess of air should be for the minimum heat losses in a given furnace.

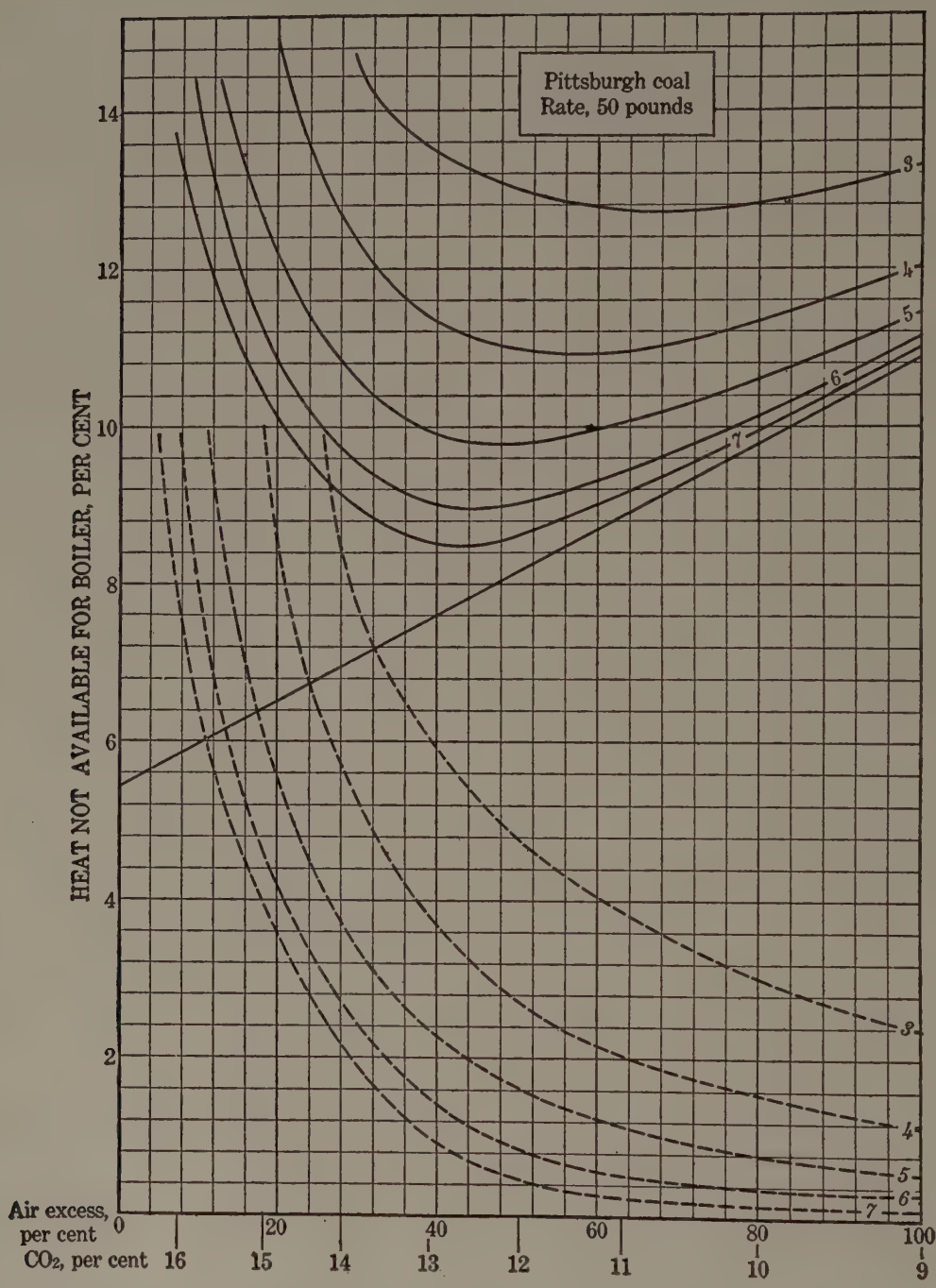


FIG. 51

Effect of air supply on the two principal sources of heat loss in a steam-generating apparatus as shown by tests of Pittsburgh coal; rate of firing, 50 pounds. The straight inclined line indicates the increase in quantity of heat absorbed in heating the air supply from atmospheric temperature to the temperature of steam in the boiler. The dotted curves show percentage of heat not developed, owing to incomplete combustion, in a furnace having the ratio of combustion space to grate area indicated by the figure near each curve. The solid-line curves represent the sum of the heat losses shown by the straight line and each of the dotted curves, and show what the excess of air should be for the minimum heat losses in a given furnace.

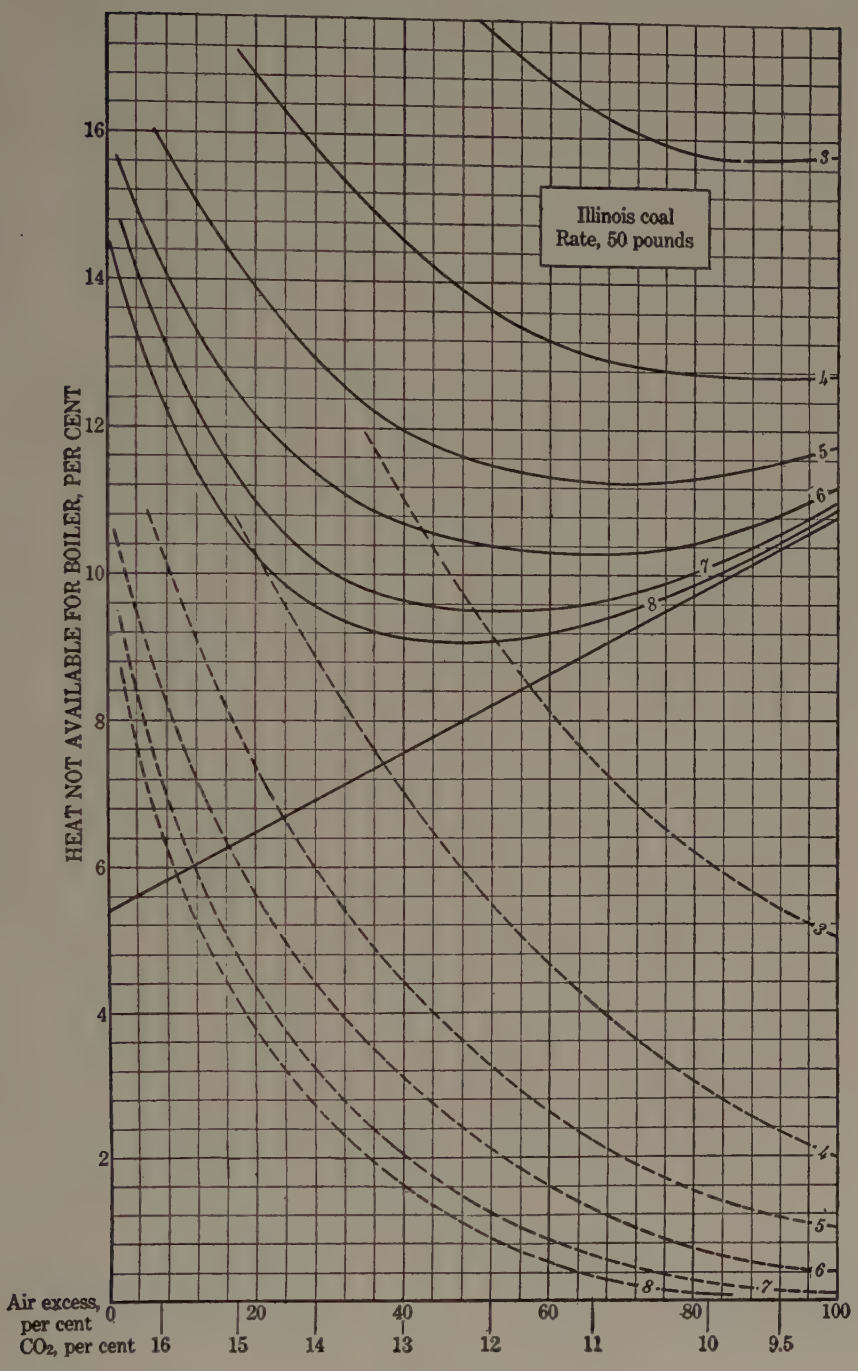


FIG. 52

Effect of air supply on the two principal sources of heat loss in a steam-generating apparatus as shown by tests of Illinois coal; rate of firing, 50 pounds. The straight inclined line indicates the increase in quantity of heat absorbed in heating the air supply from atmospheric temperature to the temperature of steam in the boiler. The dotted curves show percentage of heat not developed, owing to incomplete combustion, in a furnace having the ratio of combustion space to grate area indicated by the figure near each curve. The solid-line curves represent the sum of the heat losses shown by the straight line and each of the dotted curves, and show what the excess of air should be for the minimum heat losses in a given furnace.

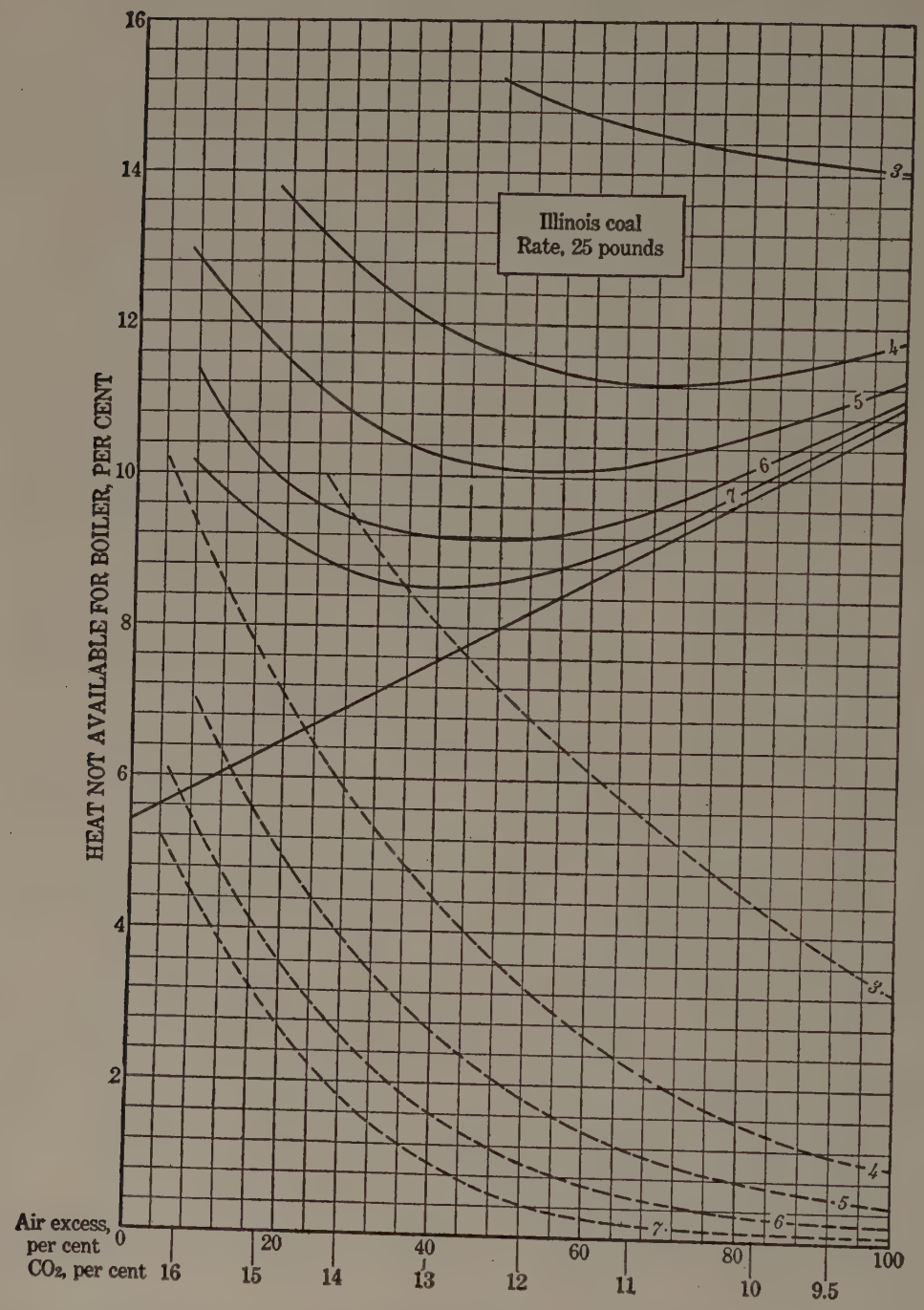


FIG. 53

Effect of air supply on the two principal sources of heat loss in a steam-generating apparatus as shown by tests of Illinois coal; rate of firing, 25 pounds. The straight inclined line indicates the increase in quantity of heat absorbed in heating the air supply from atmospheric temperature to the temperature of steam in the boiler. The dotted curves show percentage of heat not developed, owing to incomplete combustion, in a furnace having the ratio of combustion space to grate area indicated by the figure near each curve. The solid-line curves represent the sum of the heat losses shown by the straight line and each of the dotted curves, and show what the excess of air should be for the minimum heat losses in a given furnace.

under a boiler, Fig. 53 has been prepared. This figure gives the conditions for the best results when burning Illinois coal in the experimental furnace at the rate of 25 lbs. per sq. ft. of grate per hour. Comparison of Fig. 53 with Fig. 52 shows that with the lower rate of combustion the minimum heat losses occur with somewhat smaller excess of air and the losses are a little lower.

"Fig. 54 shows the relation between the size of the combustion space and the percentage of excess air giving the best results under a steam boiler. The figure consists of three separate diagrams having common abscissas, each diagram giving the relation for one of the coals tested. The diagram for the Illinois coal, given at the top of the figure, has two curves, one for a rate of combustion of 50 lbs., and one for a rate of 25 lbs., of coal per sq. ft. of grate per hour. The other two diagrams show only one curve for a rate of combustion of 50 lbs. The scale on the left gives the percentage of excess air and the scale on the right the corresponding percentage of CO_2 in the furnace gases. The size of the combustion space at the bottom of the chart is given by the three scales. Reading from the top the first scale gives the combustion space in cu. ft., the second scale below gives the number of cu. ft. of combustion space for each sq. ft. of grate area, and the third scale is the average length of the path of gas travel through the combustion space.

"The most important feature shown by Fig. 54 is that different furnaces and different fuels require different percentages of excess air to give the best results. This means that there is no one definite percentage of CO_2 in the furnace gases that will give the best results in every furnace burning any coal. *Some furnaces and some fuel may give best results with high percentages of CO_2, whereas others may have to be operated with a comparatively low CO_2 content.* Fig. 54 may furnish a guide as to the probable best CO_2 content for a given furnace and a given coal."

In view of the above the following is pertinent. "The bent tube type *automatically gives a large combustion chamber,* while in the horizontal type the combustion chamber must all be supplied by raising the boiler, making space requirements above the floor line practically the same from both types."—W. N. Flanagan, as quoted in footnote to Sect. 136.

159. CO_2 Alone Not a Reliable Index of Efficiency. Besides proving the necessity of large furnace volume for good combustion and high boiler ratings, the above exposition shows that a high percentage of CO_2 *alone* does not necessarily indicate high fuel efficiency, a fact seldom realized. "The CO_2 record is but *one link* in a complete chain, and there are circumstances under which its indications are no guide at all to the thermal efficiency being obtained in the plant."—*Power,* May 10, 1921, p. 750, High percentage of CO_2 and large furnace volume must go together. "With the large combustion chambers coming into vogue nowadays, the old assumption that 10 or 12% CO_2 is all that pays becomes obsolete. If we design our furnaces so that flame terminates before the gas enters the tubes, or soon thereafter, and we have the boiler heating surface so exposed that the maximum possible amount of heat is radiated to it, then the standard of good performance is the burning of the fuel with 15% or at the very most 25% of excess air, and the CO_2 maintained should be around 15%.—Victor J. Azbe in *Boiler Plant Efficiency,* A.S.M.E. Transactions for 1921.

Another reason why the percent of CO_2 is an unsafe basis for figuring economy is the practical impossibility of obtaining a reading not subject to large percentage of error. It is about as difficult to get a sample which gives a *true average* as it is to do the same thing when measuring flue gas temperature as shown in Sect. 179. Read Strunk's Article, p. 166 of *Power,* Jan. 30, 1923.

160. Importance of Keeping the CO_2 Reasonably Constant. This is pointed out by Azbe in the paper above quoted, as follows:—"A somewhat overlooked but also very important factor affecting boiler plant economy is 'constancy.' The percentage of CO_2 may fluctuate during the day from high to low, but if for the whole day a 10% *average* is taken, it will be found that, for a number of reasons, the efficiency will not be nearly so good as when 10% of CO_2 is *constantly* maintained. Therefore the average CO_2, when it fluctuates, is an improper measure of the loss but at the same time a good indicator of improper conditions." That is, the loss when operating *below* the 10% average will more than offset the gain when operating above that average.

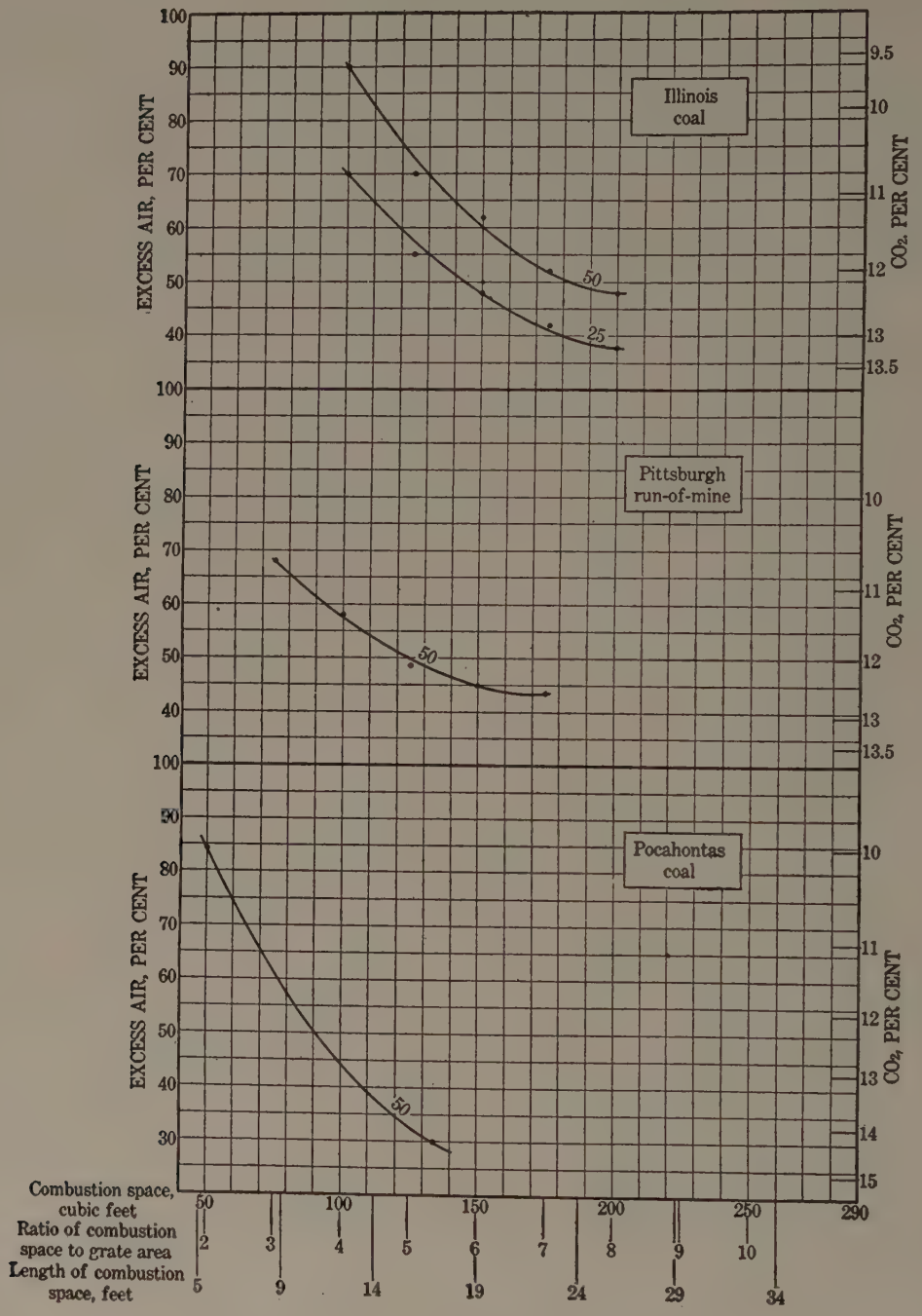


FIG. 54

Curves showing percentage of excess air giving the minimum heat losses in burning Pittsburgh, Pocahontas, or Illinois coal in various sizes of combustion space. Proportions of combustion space given by the scales at the bottom. Scale at right indicates percentage of CO_2 in furnace gases for any given excess of air shown by scale at left. Figure near each curve indicates the rate of firing the coal in pounds per square foot of grate per hour.

161. The Height of Furnace From Stoker Grate to Tubes depends not only on the kind of fuel to be burned, as later shown, but largely on the design of the boiler. It is therefore impossible to make specific statements without naming the particular boiler to which they apply, which is outside the purpose of this book. In general, header types with staggered tubes slightly inclined from the horizontal require quite higher furnaces than most of the cross drum curved tube designs. This is recognized in sundry city ordinances, but the most satisfactory way for the reader to post himself properly on this detail is to consult a table of minimum heights issued by a joint committee of boiler and stoker manufacturers, a copy of which is printed on p. 78 of *Power*, January 10, 1922, and also in Bulletin No. 2, November 1921, issued by Laclede-Christy Clay Products Co., St. Louis, Mo. As this table lists by name those boilers in general use it cannot appropriately be reproduced here.

The proper height having been provided, the next essential is to supply the necessary furnace volume, which will now be discussed.

162. Relation Between Furnace Volume and Heating Surface. On p. 79 of Bulletin 135 just cited is given our Table 5, showing the relation between grate surface, combustion rate, and quantity of air used for combustion, for three kinds of coal. Converting this into easier shape for general use, and checking the same by the results of experience, it will be found that for good results it is essential to provide in hand fired boilers 1½ cu. ft. of furnace volume for each 10 sq. ft. of boiler surface whenever possible, and for boilers which are stoker fired 2 cu. ft. or *more* should be provided. For most coals and for oil fuel this will give good results up to 175 to 200% of rating, but for higher ratings more volume is always desirable, and often essential especially for highly volatile fuel. For operating at 250% to 275% of rating when burning the volatile coals of Illinois, Indiana, Iowa, and of the West and Southwest, *not less than* 3 cu. ft. of furnace volume per 10 sq. ft. of heating surface should be provided if satisfactory results are expected. Some excellent information on this is contained in *Securing Better Combustion*, by Green Engineering Co., East Chicago, Indiana.

163. "Furnace volumes vary from 1 cu. ft. per lb., of coal burned per hour down to less than 0.1 cu. ft. in some cases. The lower amounts, of course, do not represent the entire combustion space because combustion under such conditions extends among the tubes, at times for a considerable distance, but this is not what is to be desired. The larger amounts are used with powdered fuel and are necessary because the solid particles burning are relatively large and require a larger combustion chamber for their gasification and combustion than is the case when gasification, and to a certain extent mixing with air, take place on a grate. With Illinois coal and a combustion chamber of 0.5 cu. ft. per lb. of coal burned, very good

TABLE 5.

RELATION BETWEEN GRATE SURFACE AND FURNACE VOLUME.

Completeness of combustion, per cent of undeveloped heat.	Rate of combustion, pounds per square foot of grate per hour.	Excess of air (per cent).	Cubic feet of combustion space per square foot of grate area.		
			Pocahontas.	Pittsburgh.	Illinois.
1	2	3	4	5	6
5	50	50	2.7	2.9	4.3
3	50	50	3.2	3.7	5.3
2	50	50	3.6	4.4	6.3
1	50	50	4.0	5.6	8.9
0.5	50	50	4.8	6.8	11.9
5	25	50	2.0	2.2	3.5
3	25	50	2.3	2.7	4.35
2	25	50	2.7	3.1	5.1
1	25	50	3.4	4.0	6.2
0.5	25	50	4.0	5.0	7.1

results should be obtained provided the arrangement is correct. The aim is to have the gas completely burned and no flame entering the first tube pass. To accomplish this, *more* than mere furnace volume is necessary. There are such things as effective and ineffective combustion space."—Victor J. Azbe in *Boiler Plant Efficiency*, A. S. M. E. Transactions, 1921.

164. Illustrations from Prominent Plants. The latest installation of Detroit Edison Co. is provided with auxiliaries to operate up to 300% of boiler rating, but no economizers are used. The furnaces contain 3.83 cu. ft. of volume per 10 sq. ft. of boiler surface. See *Power*, Sept. 21, 1921.

In *Power* for January 3, 1922, p. 4 is a sum-

mary of furnace volumes per 10 sq. ft. of boiler surface as follows:—

Duquesne Light Co., Pittsburgh, without economizers, 3.45 cu. ft.

Philadelphia Electric Co., Delaware Station, without economizers, but with furnaces arranged for burning bituminous coal on stokers, or firing with oil or pulverized anthracite or bituminous coals, 4.8 cu. ft.

Hartford, Conn. Electric Co., boilers with economizers whose surface is 20% of that of the boilers, 4.5 cu. ft.

Penn Public Service plant, Johnstown, Pa., without economizers, 3.25 cu. ft.

United Electric Light & Power Co., New York, Hell Gate plant, without economizers, 4 cu. ft.

plants, 3.62 cu. ft.; with underfeed stokers, mean of 8 plants, 3.86 cu. ft.; with pulverized coal, mean of 3 plants, 5.39 cu. ft.

In his investigations the author naturally found wide discrepancies between the volumes used at the different plants investigated, but so far as the available data permitted he summarized them in Table 6A which presents the matter in a more workable shape than has previously been done.

165. At the meeting of American Electric Railway Engineering Association, October 1920, statistics as to operating costs were presented. A questionnaire was sent to many sources and the replies were tabulated. Among the data thus gathered was a statement as to furnace volumes found necessary for different fuels.

TABLE 6A.

B. T. U. FIRED PER HOUR PER CUBIC FOOT OF FURNACE VOLUME AT EFFICIENCIES OF ABOUT 80 PER CENT WITHOUT ECONOMIZERS.

FUEL-BURNING SYSTEM	B. T. U. PER CU. FT. OF FURNACE VOLUME
Pulverized coal	22,000
Chain-grate stokers	37,500
Underfeed stokers	64,000
Locomotives	70,000
Oil—steam atomization	85,000
Scotch marine boiler, hand-fired	144,000
Oil—mechanical atomization	176,000

Lakeside Plant, Milwaukee, Wis., with economizers and fired with pulverized coal, 5.4 cu. ft. or 0.74 cu. ft. per lb. of Illinois coal burned per hour when operating at 200% of boiler rating.

Commonwealth Edison Co., Chicago, Calumet Station, no economizers, but with forced draft chain grate stokers having a ratio of grate to boiler surface of one to forty, 18 cu. ft. furnace volume per sq. ft. of grate, or 4.5 cu. ft. per 10 sq. ft. of boiler surface.

In *Mechanical Engineering* for May, 1923, Mr. E. B. Ricketts published a timely paper entitled *Boiler Furnace Design,* the essentials of which were also reprinted in *Power,* April 17, 1923. The author presents tables of furnace volumes in sundry recent and some older plants. The recent installations show cu. ft. of furnace volume per 10 sq. ft. of boiler surface as follows:—With chain grate stokers, mean of 6

The information thus gathered is presented in Table 6B, but the volumes therein given are not as great as often found necessary when operating at high rating, particularly with coals from Mississippi valley and west thereof, and for oil fuel.

166. Furnace Volume for Burning Oil. In *Boiler Plant Efficiency,* A. S. M. E. Transactions for 1921, Mr. Azbe says:—"Fig. 55 shows test results made by the U. S. Navy Department. The large combustion space is primarily the reason why an efficiency of 66.5% is possible with a rating of 400%. With an ordinary installation and such high rating, flame would be noticeable in the uptake, flue gas temperature would exceed 1000 deg. Fah. and boiler efficiency be decidedly less than 50%."

On the same subject E. J. Billings, of Henry L. Doherty & Co. says, p. 418 of *Power,* March 14, 1922:—"It is quite essential for maximum

boiler efficiency that combustion be practically completed before the gases come into contact with the cool surfaces of the boiler. This necessitates ample room for flame travel and a combustion space of not less than 50 and preferably 65 cu. ft. or more if possible, per 1000 pounds of steam produced per hour." This means 1.6 to 2 cu. ft. of furnace volume to each 10 sq. ft. of boiler surface when operating *at rating only*, and proportionately more at higher ratings, an amount which can be got only by setting the boiler higher than usually done. But such large volume and high setting will pay if the boiler is to be operated at the ratings now known to produce the highest efficiency of Capital.

TABLE 6 B.

AVERAGE FURNACE VOLUME, CU. FT. FOR A BOILER RATED AT 600 HP. FOR DIFFERENT FUELS, FIRING EQUIPMENT, AND RATES OF OPERATING.

Kind of Fuel	Anthracite No. 3 Buckwheat			Anthracite Culm			Lignite			Bituminous Slack			High Grade Semi-Bitum.			Bituminous		
% Boiler Rating Wanted	100	200	300	100	200	300	100	200	300	100	200	300	100	200	300	100	200	300
	Fired by Powdered Fuel Burners																	
Cu. Ft. Furnace Volume	1500	2700	4050	1500	2700	4050	1950	3600	5400	1650	3000	4500	1500	2700	4050	1650	3000	4500
	Fired by Oil Fuel			Fired by Under-feed Stokers														
Cu. Ft. Furnace Volume	500	850	1300				1100	1500			1050	1250		900	1050		1050	1250

A. D. White, Chief Operating Engineer, Standard Oil Co. of N. Y. says in *Combustion*, April, 1922, p. 176 that "A furnace volume of 2 cu. ft. per boiler H.P. *developed* will show the best efficiency, provided the air ports to the furnace are so arranged as to give an even distribution of air to the furnace and just sufficient for good combustion."

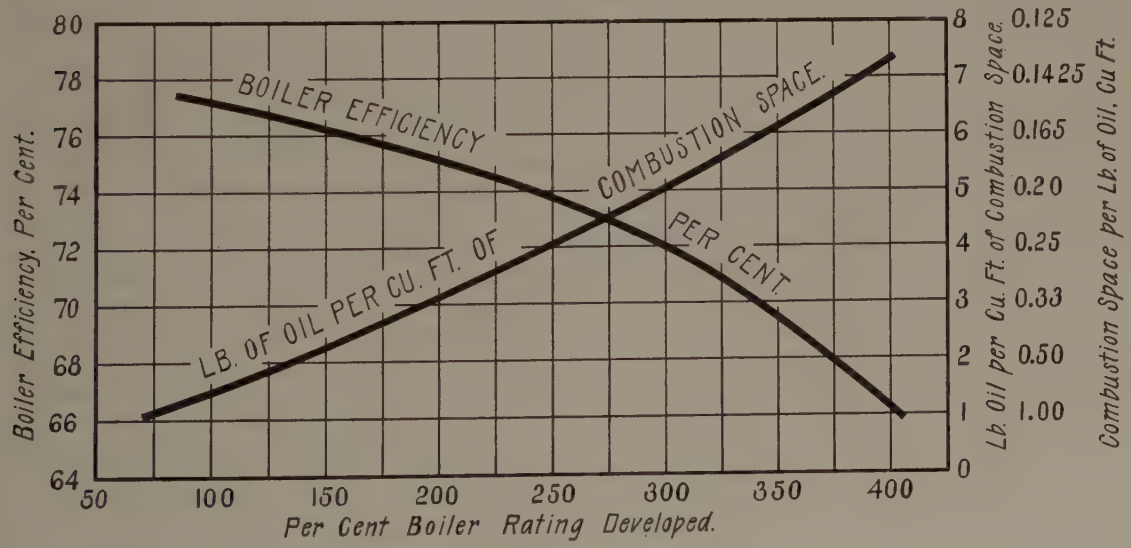


FIG. 55. FURNACE VOLUMES FOR BURNING OIL

167. But unless the speed of circulation in the boiler is correspondingly fast, such increase of furnace volume is useless. "An interesting fact in connection with oil fuel is that approximately 80% of the heat transfer takes place in the first pass of the average water tube boiler which, of course, subjects this portion of the surface to an intense heat which is more trying to the tubes than the more evenly distributed heat from a local fire. *Unless this fact is borne in mind, and both furnace and burners especially designed for a good distribution of heat, boilers should not be forced beyond about 150% of their nominal rating, when using this kind of fuel."—Increasing Boiler Capacity,* by Chas. L. Hubbard, in *National Engineer,* November 1921, p. 569. The rapid circulation in the Kidwell boiler makes it the ideal design for firing with oil fuel, as it can be safely operated far beyond the limit above mentioned.

TABLE 7.

RELATION BETWEEN CO_2 AND EXCESS AIR WHEN BURNING OIL FUEL.

Per cent CO_2 by volume as shown by analysis dry chimney gases	Light oil C, 84 per cent; H, 13; S, 0.8; N, 0,2; O, 1; H_2O, 1		Medium oil C, 85 per cent; H, 12; S, 0.8; N, 0.2; O, 1; H_2O, 1		Heavy oil C, 86 per cent; H, 11; S, 0.8; N, 0.2; O, 1; H_2O, 1	
	Pounds of air per pound oil	Ratio air supply to chemical requirements	Pounds of air per pound oil	Ratio air supply to chemical requirements	Pounds of air per pound oil	Ratio air supply to chemical requirements
4	51.40	3.607	51.93	3.704	52.45	3.803
5	41.31	2.899	41.71	2.975	42.12	3.054
6	34.58	2.427	34.90	2.490	35.23	2.554
7	29.77	2.089	30.04	2.143	30.31	2.198
8	26.17	1.836	26.39	1.883	26.62	1.930
9	23.37	1.640	23.56	1.680	23.75	1.722
10	21.12	1.482	21.29	1.518	21.45	1.555
11	19.83	1.391	19.43	1.386	19.58	1.419
12	17.76	1.246	17.88	1.276	18.01	1.306
13	16.46	1.155	16.57	1.182	16.69	1.210
14	15.36	1.078	15.45	1.102	15.55	1.127
15	14.39	1.010	14.48	1.033	14.57	1.056

168. **Preheating the Oil.** Mr. White, above quoted, states that "The preheating of fuel oil is a point that is quite frequently neglected and quite often we see oil being fed to the boiler at a temperature of 120 to 130 deg. F. If the fuel oil is reheated to a temperature of 200 deg., it requires less steam to atomize the oil, and the oil breaks up much easier. In this way good combustion is obtained at fairly high rates of vaporization through each burner. That is, a burner that will handle only 250 pounds of oil per hour at 130 deg. temperature, will vaporize 400 pounds of oil per hour when the oil is preheated to 200 deg. or more." It must be noted that if the oil is heated to 212 deg. any water in it will be converted into steam which may pass out in slugs and extinguish the flame. This is dangerous, hence 200 deg. should not be exceeded.

169. **Relation Between CO_2 and Amount of Excess Air When Burning Oil.** Mr. C. R. Weymouth in *Unnecessary Losses in Firing Fuel Oil,* A. S. M. E. Transactions, 1908, classified oil as light, medium and heavy, and computed that the amount of air chemically required to burn 1 lb. of these with *no excess* would be 14.25, 14.02 and 13.79 lbs. respectively, from which Table 7 was computed. From this, if the CO_2 content be known the pounds of air supplied per pound of oil, and the percentage of excess

air, can be at once obtained. Intermediate values may be obtained by interpolation.

170. For Burning Gas, large furnace volume is equally necessary for good combustion and high ratings. Thus, boilers arranged for burning blast furnace gas often cannot develop even rating without difficulty, due mostly to deficient furnace volume. But if 2½ to 3 cu. ft. of furnace volume per 10 sq. ft. of boiler surface be provided, and a good burner be installed, such boilers can develop 135 to 150% of rating continuously, and 180 to 200% in peaks. See *Steam Power from Blast Furnace Gas,* in *Power,* November 8, 1921.

As to the quantity of gas produced W. S. Hall in *Journal of the Western Society of Engineers,* May, 1922, says:—"A modern 600-ton blast furnace uses approximately 560 tons of coke each 24 hours. In the production of 600 tons of iron in 24 hours, approximately 70 million cubic feet of gas are produced. At the rate of 90 B. T. U. per cu. ft. this is equivalent to approximately 250,000,000 B. T. U. per hour."

171. Consequences of the Facts Above Presented. It follows that different fuels may need widely different furnace volumes and arrangement, so that while a boiler and furnace may produce excellent results with one kind of fuel, changing over to a more volatile fuel might cause serious trouble. With such fuel and insufficient furnace volume to burn it properly, not only will there be large loss due to volatile matter passing off unburned, but combustion will continue beyond the furnace, and flames extend through the tubes and far along the gas passages, unless the tubes are staggered. In the latter case dense smoke will be formed, the loss due to unconsumed volatile will be high, the gas passages will accumulate soot to a degree which will cause much trouble and the tubes will be so coated that their efficiency is considerably reduced. The final result will be equivalent to *moving the furnace just that much closer to the breeching* so that the exit temperature of the gases will be high, or even excessive.*

172. The moral of all this is that *when a boiler purchase is decided upon the very first step is to settle what fuel is generally to be burned, and what type and size of stoker, and general furnace arrangement are to be used to burn it.* Full consideration should be given to the likelihood of having to change over to a very volatile coal, and if disappointment is to be avoided *the furnace volume and arrangement should be such as to burn that coal with high efficiency.* A furnace with large volume will burn high grade low-volatile coal with great success, *but the reverse is not true.* "The furnace of a boiler is simply a generator of units and gas. It makes no difference whether the fuel be coal, coke, oil or gas, the function of the furnace is the same. It is to produce intensely heated gases that conduct the heat to the transmitting surfaces. Indeed, it is essential for the sake of analysis to detach furnace operation from all other operations of the boiler. Think of the concentration of heat that is desired and the composition of products that is most effective. Then will the principles of efficient operation become clear. Then and then only will the problem of heat absorption in the boiler tubes start with the most favorable conditions for efficient work in that stage of the process."—*Power,* September 13, 1921, p. 422.

173. After these details are settled, then, *and not till then,* should the boiler be selected to suit. While this is self-evident, *it is precisely the reverse of what is usually done.* Almost invariably bids are asked on boilers, an order is placed, the stoking and furnace arrangements

*The importance of this subject justifies the reproduction of the following from *Boiler and Furnace Economy* by Dr. D. S. Jacobus, in *Mechanical Engineering,* December 1921, which appeared after the above was written:—

"There has been a gradual increase in furnace volumes. In the burning of blast furnace gas we now furnish at least 2 cu. ft. of furnace volume per rated boiler HP., which is over double that used in the older practise. For some coal fired boilers fitted with forced blast chain grate stokers we are supplying about 4 cu. ft. per rated HP. The gas fired boilers are operated at about 200% of rating as a maximum and the coal fired boilers at over 300%, so that in each case we are supplying about 1 cu. ft. of furnace volume per maximum developed HP. In case of powdered fuel furnaces the furnace volume of the latest installation is about 2 cu. ft. per *developed* HP. These figures are for the larger furnaces used in stationary practise, and in some instances with smaller furnaces a higher capacity may be developed per cu. ft. of furnace volume. It is seldom, however, that over 2 HP. is developed in stationary practise per cu. ft. of furnace volume. * * * High capacities of the sort with relatively small furnaces can only be secured with the cleanest of feed water, and *it is certainly advantageous to use the larger furnaces in stationary practise, as by so doing it is easier to operate without an undue amount of tube troubles,* the trouble through the collection of slag on the exterior of the tubes will be diminished, and the combustible gases can be more thoroughly consumed within the furnace chamber."

are then made *to suit the boiler and not the fuel,* and the error in the whole procedure is not discovered until the plant is operating and the furnace is found to be improperly designed for the fuel.

174. As further illustrating this, note the following:—"Too frequently superheaters are designed and fabricated before it is possible to determine operating conditions. Either the purchaser does not know what fuel, furnace or stoker he will use, or the capacity at which he will operate, or his ideas on the subject change between the time of purchase and the time of installation. In the case of new installations even with fuel, furnace, stoker and capacity known, the superheater builder cannot know the operating conditions and may design his apparatus for what is ordinarily considered average conditions for the class of plant in which the superheater is to be installed. The superheat may then fall below or above the anticipated amount because of operating conditions."—*Steam Superheaters,* in *Journal of the Engineers' Club,* Philadelphia, June, 1921. What is here said as to superheaters applies equally to stokers and boilers.

175. Advantage of Radiant Heat. To secure high fuel efficiency it is necessary (other things being equal) so to arrange the furnace that the boiler can absorb the greatest possible amount of radiant heat, because radiant heat passes directly from the incandescent fuel bed to the boiler *without affecting the temperature of the intervening gas,* and is absorbed by the heating surface with *practically* 100% efficiency. The percentage of the total heat transmitted by radiation varies from a small amount up to 50% or more according to the furnace design. The greater the amount of heat so transmitted, the less the amount which enters the gases, hence the lower the furnace gas temperature will be, and the less the liability of overheating and deteriorating the furnace walls.

It follows that arches over the fire, by screening the radiant heat from the tubes, reduce the percentage of heat absorbed by radiation, hence many may quickly conclude that they should be condemned and avoided. That would be true *if the same amount of heat could be produced with equal combustion efficiency when the arches were omitted,* but for many fuels such result is impossible of attainment. Therefore in such cases arches are essential for developing combustion efficiency, and what they lose by reducing the percentage of heat transmitted to the boiler by radiation they more than make up by increased efficiency of combustion, and thereby gain high capacity besides.

In view of the above the following statement is of supreme importance and expresses a fact now being realized by designers of plants to develop high capacity. "The bent tube boiler not only has *greater effective heating surface, but also has a larger amount of heating surface exposed to direct radiation from the fire, less steam blanketing (or pocketing) of the tubes as previously explained,* and due to the low resistance to gas flow, the length of gas travel and the velocities can be so adjusted as to permit a bent tube boiler to compare with any other type on an equal draft loss basis."—W. N. Flanagan as quoted in Sect. 155.

176. For Wet or Highly Volatile Fuels arches over the fire are absolutely essential for drying out moisture or igniting the distilled gases, if any worth while capacity is to be developed. Fine anthracite, coke breeze and similar fuels can be burned with high efficiency and capacity only on types of stokers provided with brick arches sufficient to cause ignition of the gases. Other classes of fuel, such as low grade middle western coals having a low fusing point ash, are also burned to advantage on stokers of the traveling grate type requiring arches for ignition purposes, but in such cases also the furnace design should be so arranged as to permit the largest possible percentage of heat absorption by radiation. Other features affecting the efficiency of the boiler and stoker as a whole may *make it inadvisable so to design the setting as to expose the full area of the fuel bed to radiant heat absorption,* but in general, after sufficient provision has been made, by means of arches or their equivalent, to ignite the volatile matter and secure high capacity and combustion efficiency, then the boiler efficiency will be increased by so arranging the remaining parts of the furnace that the maximum possible percentage of heat is transmitted to the boiler by direct radiation.

The matter is thus summed up on p. 133 of Bulletin 18, Bureau of Mines, *The Transmission of Heat into Steam Boilers*:—"It is obvious that if two boilers have exactly similar construction and baffling, the gases in the one which is so set that it receives more heat by radiation from the furnace will have the *lower initial and final temperatures,* and the efficiency of this boiler will be the higher. This means that any heat

which the boiler gets directly by radiation is *a clear gain.* Of course, the presumption is that the combustion and air supply is the same in all cases." Victor J. Azbe in *Power Plant Efficiency*, A. S. M. E. Transactions for 1916 says:—"Exceedingly high furnace temperatures have no real advantage and several disadvantages, therefore *heating surface exposed directly to the fuel bed to reduce the furnace temperature* will not only cause a decrease of the slagging effect upon the firebrick, and thus increase the CO_2 possible to maintain, but will also increase the efficiency of the boiler due to the heat radiated directly to it, and will increase the boiler capacity without increasing the flue gas temperature." This is now becoming better understood. A joint committee of stoker and boiler manufacturers prepared a table showing the height of setting they recommend for different types of boilers (see Sect. 161) and stated that, "A most important point in the matter of minimizing renewals of brickwork is that the first bank of tubes be so arranged that it can absorb by direct radiation a large portion of the furnace heat. This greatly reduces the temperature of the firebrick without a corresponding reduction in boiler efficiency."—*Firebrick Troubles; Causes and Remedies*, in *Power*, January 10, 1922.

177. Boilers for Low Head Room. It is therefore apparent that to obtain sufficient furnace volume and distance between the fire and the boiler surface, ample height is necessary, and that low head room in a boiler plant automatically insures inefficient furnaces, wastes money and increases the smoke nuisance. City ordinances frequently prohibit the installation of boilers with deficient furnace height, which is a move in the right direction. Every boiler room should be designed not only for purpose of installing furnaces of the proper volume, but to give easy access to all overhead piping, and to make the room comfortable for operatives. Considering furnace volume first, and the other factors above named, the *least* height that should be considered today to provide for boilers of *any size and consequence* is 27 to 30 feet from floor to bottom of roof truss. In certain kinds of buildings, however, such height is not always possible, hence KIDWELL BOILER CO. has designs which can be installed in rooms 20 feet high in the clear, and still leave space above for piping. For lower head rooms proper furnace volume cannot be got with Kidwell Two-Flow Ring-Circuit boilers, and for such cases the Company furnishes another design which is also superior to previous ones as to delivering dry steam. Particulars will be furnished upon receipt of information as to available space and other essential requirements.

178. Flue Gas Temperature Not a Reliable Measure of Efficiency. This must be understood as a great deal of nonsense has been written on this subject. To prove it, note lines A and D in Fig. 4, then consult the records of the tests as named in Sect. 75, from which it will be found that for similar ratings the flue gas temperatures for line D were invariably lower than those for line A, *yet the efficiencies were lower also!* Similarly, we have seen tests made on the same equipment by same experimenters and with identical fuel, and for identical efficiencies the flue gas temperatures differed by as much as 100 deg.* Therefore, flue gas temperature *alone* is no more of an accurate indicator of efficiency than CO_2 alone, as shown in Sect. 159. Hence explanation is needed.

In Sect. 176 it is shown that the temperature of the gas leaving the boiler is proportional to that of the gas entering the boiler; i. e., the cooler the furnace gas the lower the flue gas temperature. If this cooling be accomplished by so arranging the furnace that a large percentage of heat is absorbed into the boiler by direct radiation, that is conductive to economy as shown in Sect. 175, in which case low flue gas temperature and efficiency go together.

But admission of excess air and poor stoker performance will also cause low temperature of gas before it reaches the boiler. Failure to burn the volatile matter will produce an identical result as shown by Figs. 50 to 53. A poor setting which permits a large loss by radiation and leakage of air likewise reduces the final temperature of the gas, but such reduction is the direct result of waste. "Even the temperature of the outgoing gases is not always a guide to efficiency since that temperature is dependent upon the amount of excess air used for combustion, upon the rapidity of combustion, upon air infiltration, upon moisture and hydrogen in the coal, etc., as well as upon the arrangement of the heating surface."—W. N. Flanagan as quoted in Sect. 155.

Therefore the prevalent opinion that flue gas temperature alone is a reliable index of fuel

*For example, note tests 4 and 6 on p. 245 of *Combustion*, May 1922.

efficiency is in error, hence the absurdity of the rather common procedure of asking boiler manufacturers to *guarantee* flue gas temperatures, *often when even the stoker, grade of fuel and many other essential factors are unknown!* It should therefore be understood that what is said toward end of Sect. 105 as to fuel efficiency applies here also. Subject to the limitations below defined, any competent designer can, if all the factors are known, produce a boiler to give any desired flue gas temperature *provided the purchaser of such boiler is not concerned with either its cost or its efficiency as to Capital!*

179. Difficulty of Measuring Flue Gas Temperature. There is another factor of great importance and that is the impossibility of getting a measurement of flue gas temperature which is even approximately accurate. As this will doubtless astonish many, the following proof of it is quoted from p. 305 of Bulletin 23, Bureau of Mines, *Steaming Tests of Coals*:—"The following is an actual case. * * * Recently one of the authors visited a Pittsburgh plant where tests were being conducted with a special furnace equipment. The engineer in charge showed him tabulated results of a boiler test made by the equipment. These were some of the items:—Gauge pressure, 162 lbs.; flue gas temperature, 386 deg.; efficiency, 78%; temperature corresponding to 162 lbs. pressure, 371 deg. "The above figures show that the flue gas was only 15 deg. hotter than the water in the boiler. This would be a very good heat absorption indeed *if the temperature measurments were correct.* However, on investigation it was found that the thermometer was inserted among the tubes at the end of the third pass of the usual Babcock & Wilcox 3-pass boiler. *What the thermometer really did measure was the temperature of the surrounding tubes. The actual temperature of the gases at the place was perhaps 200 to 300 deg. higher.*" This exposes the fallacy in many low flue gas temperatures concerning which much noise is often made.

180. Measurements subject to such wide limits of error, and which are so easily manipulated to show favorable results, are useless except as rough guides, and are certainly not entitled to more than a small fraction of the confidence usually reposed in them. As evidencing this, one of the most capable authorities in such matters once remarked to us that "To ask a man to make a *correct* measurement of flue gas temperature is on a par with asking him to determine the depth of the Mississippi or any other rapidly shifting river."

181. What is a Reasonable Flue Gas Temperature? Besides the factors mentioned above a number of others influence the flue gas temperature. Other things being equal, the flue gas temperature when burning coke breeze or fine anthracite will be quite higher than when firing with good bituminous coal, while oil should at identical ratings show a lower exit temperature than coal. Therefore a flue gas temperature which would be satisfactory for one fuel might not be so for a different fuel.

182. If all the above be kept in mind it is possible to construct a chart to indicate *very roughly* the character of performance corresponding to any flue gas temperature. Mr. Azbe in *Boiler Plant Efficiency*, A. S. M. E. Transactions for 1921, has done this:—"The temperature of the escaping products of combustion determines fuel loss to a great extent, but what is low and what is high flue gas temperature? The lack of a suitable measure and standard has prevented proper comparison of results and has also caused a certain lack of incentive for improvement. The writer, in his effort to evolve a measure, has drawn Fig. 56 based on 150 different boiler tests. Each dot represents the average flue gas temperature at the average rating developed in each test. The space is divided into sections varying from exceptionally good to exceptionally bad results, with the slope of the line following as closely as possible the increase of flue gas temperature with the increase of boiler output of a number of boiler test series. To obtain a low flue gas temperature, it is necessary that the heating surface be clean."

No such chart can be more accurate than the data upon which it is based, hence any use that may be made of it must consider the above stated facts both as to the chart and the measurements to be checked up in comparison with it.

183. Hand Firing Versus Stokers. Nearly all of the credit for the great increase in combustion efficiency which has been attained during the last 25 years unquestionably belongs to the *stoker designer and engineer!* Boiler manufacturers often opposed progress in this direction, and even yet some are far from active in seconding the efforts of stoker engineers to drive boilers at higher ratings and thus reduce the boiler investment. This is natural, as few boilers are so designed as to operate with safety at heavy overloads and under the high furnace

temperatures now developed by good stokers. None the less any one operating a plant of other than small size, and firing the same with coal, cannot under present conditions as to labor and fuel costs afford to fire by hand if he desires the greatest return for the least money. In fact, the increased steam output which can often be got by installing stokers will so decrease the initial boiler investment that the saving thereby made will pay for a good stoker, and thus *a plant to give a certain output at high efficiency with stokers may cost little if any more than one to give the same output with far less efficiency when fired by hand.* The reason for this is that not only can more coal be burned so as to produce a greater capacity, but also the amount of air admitted per pound of coal is greatly decreased, which fact not only increases the capacity and efficiency of the combination of boiler and stoker, but it also somewhat reduces the necessary stack diameter, and considerably reduces its height, both of which effect a saving. See Sects. 676 and 681.

184. This is confirmed in *The Generation of Power,* by D. S. Jacobus in *Journal of the Franklin Institute, December* 1910, thus:—"It is difficult to carry economically enough reserve capacity to meet the daily peaks in the load. Then again, there are exceptional peaks which occur only at rare intervals, so that a considerable percentage of the available power may be developed only for a few hours every month, or for that matter, for a few hours every year. *Modern practise leads more and more to developing higher ratings from boilers during such intervals, and a boiler should be used which, under proper operating conditions, may be driven to a capacity that is limited only by the amount of coal which can be burned in the furnace.* Again, it is desirable to use boilers that may be cut into the line quickly either from banked fires or starting from a cold state."

185. As some believe or fear that operating at such ratings causes a loss in fuel efficiency, it is to be noted that even so the efficiency of capital, or money, (Sect. 139 *et seq.*), is thereby increased, and that is the ultimate result sought. But it is seldom true that the fuel efficiency decreases when operating up to 200% of rating with a good stoker, and the contrary is often true. This is brought out in the article above cited, as follows:—"With * * * stokers, such as were described, the best efficiency is reached at slightly *above rating and remains constant to nearly double rating.* The reason is that as the rate of combustion of the coal becomes greater the furnace efficiency increases to a sufficient extent to offset the loss of heat absorptive efficiency of the boiler itself. It is therefore apparent that under these conditions the best *commercial economy* is obtained by following the practise described, and operating the boilers at double the nominal rating."

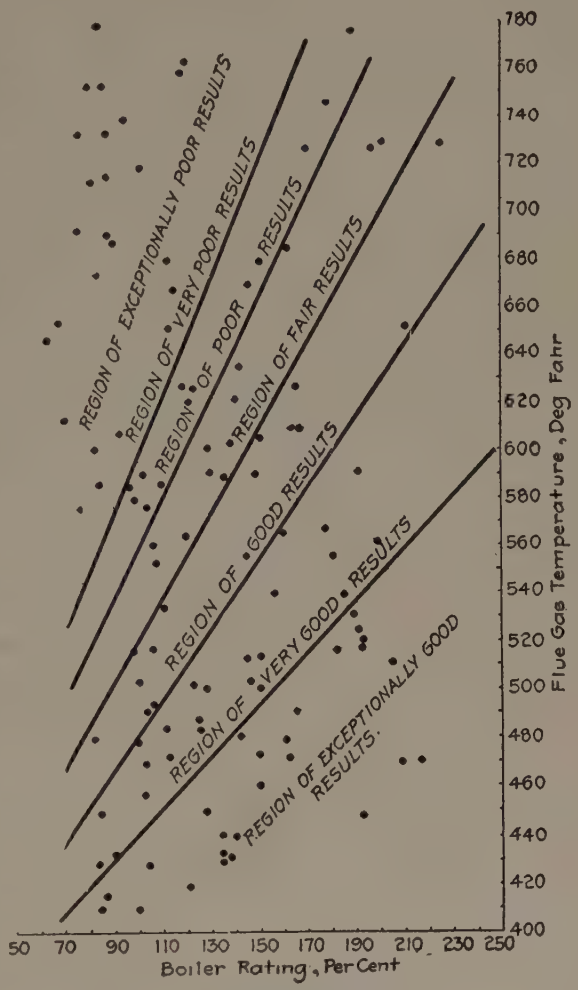


FIG. 56. AZBE'S CLASSIFICATION OF FLUE GAS TEMPERATURES

186. The author above quoted was discussing a boiler which has very restricted circulation hence is not adapted to continuous operation at high ratings. Yet, on his own statement of facts, operating at double rating causes little or no drop in fuel efficiency, and does produce the highest commercial efficiency. Therefore, the way to get the highest efficiency of invested

capital *continuously* is not only to operate the boilers far above rating, but *to do so continuously!* This is a proved fact, and the only reason why such practise is not usual is that *the boilers in current use cannot so operate without burning tubes and causing other operating troubles due to deficient water endurance surface and severely fluctuating water level!*

gineering principles, KIDWELL BOILER CO. not only has no hesitation in going on record here as to the correctness of the statements above made, but has long worked to produce a boiler designed to comply with every demand imposed by this plan, and to operate at any rating which a stoker can develop. This the Kidwell boiler does, as later shown.

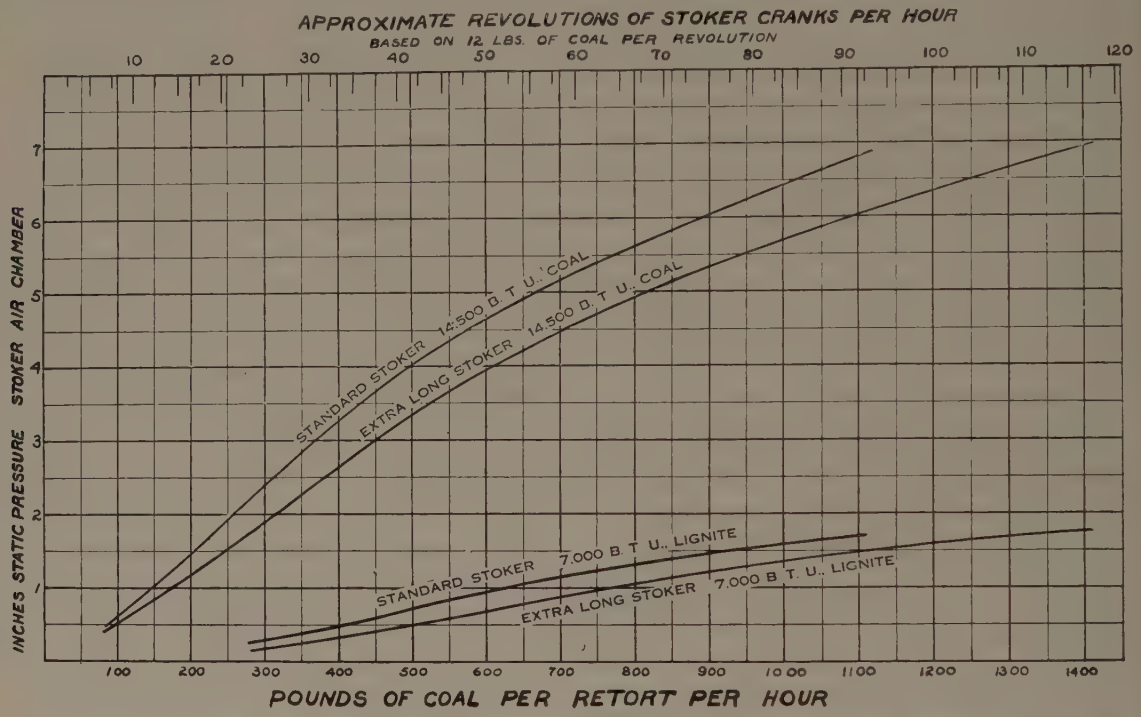

APPROXIMATE REVOLUTIONS OF STOKER CRANKS PER HOUR
BASED ON 12 LBS. OF COAL PER REVOLUTION
10 20 30 40 50 60 70 80 90 100 110 120
INCHES STATIC PRESSURE STOKER AIR CHAMBER
1 2 3 4 5 6 7
STANDARD STOKER 14,500 B T U., COAL
EXTRA LONG STOKER 14,500 B. T U., COAL
STANDARD STOKER 7,000 B T U., LIGNITE
EXTRA LONG STOKER 7,000 B. T. U., LIGNITE
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
POUNDS OF COAL PER RETORT PER HOUR

FIG. 57. SHOWING RELATION BETWEEN AMOUNT OF COAL BURNED, DRAFT REQUIRED, AND SPEED OF RILEY STOKER

Therefore, whenever this method of operation is questioned by a boiler salesman, it behooves the prospective purchaser to scrutinize every such objection with the utmost care, in order to ascertain whether the motive behind it is to benefit the purchaser, or merely to induce him to buy boilers unequal to continuous operation at high overloads, or to buy more boiler and stoker capacity than he really needs. In this connection, read all of Sects. 490 to 499.

187. While the procedure above recommended reduces the amount of boiler to be purchased it is sound engineering and financing,* and in keeping with its policy of advising its clients to *their own best interests* and on correct engineering principles, KIDWELL BOILER CO. not only has no hesitation in going on record here as to the correctness of the statements above made, but has long worked to produce a boiler designed to comply with every demand imposed by this plan, and to operate at any rating which a stoker can develop. This the Kidwell boiler does, as later shown.

Caution! To obtain results as above described it is *essential that the stoker be adapted to the fuel used.* Proper discussion of this subject requires more space than available here, but the necessity for such discussion is obviated by the recent appearance of *Mechanical Stokers,* by Worker and Peebles (see Bibliography) which merits careful reading by every one interested in stokers. A resume of some important conclusions from this volume begins on p. 547 of *Power,* April 25, 1922.

188. Speed of Stokers. Attention must be given to the speed of the stoker, and the air supply be so regulated as to cause complete combustion by the time the dump or equivalent

*See *Fuel Saving in Relation to Capital Necessary,* in *Mechanical Engineering,* November 1921. Also note statements of D. M. Meyers at end of Sect. 29, and Messrs. Azbe and Martin in Sect. 499.

device is reached, *and not before or after.* If insufficient air is admitted, or the stoker speed is too great, coke or unburned coal will be dumped into the ash pit. If the speed is too slow, or air supply excessive, the combustion will be completed too soon, and the rear part of the stoker contain only ashes which will permit a large excess of air to enter.

Each stoker maker will furnish a diagram or instructions showing the speed and air pressure corresponding to various combustion rates, or equivalent information, and every operator who is not thoroughly familiar with the subject should obtain such diagram and follow it until he fully understands every detail of the operation. Fig. 57 shows such a diagram as furnished by Sanford Riley Stoker Co. and it applies to the form of stoker shown in Fig. 178.

189. Burning Pulverized Coal. Engineers have long recognized the advantages of pulverizing coal so that it can be burned very much like oil. During the last 25 years various steps in the process have been worked out by sundry experimenters, but before these could be properly coordinated and the process be pronounced commercially successful it was necessary for some one man having the necessary technical qualifications and financial means available, to take up the work, sift out what has been done before, locate deficiencies and their remedies, and through a long series of trials bring the whole art of burning pulverized coal under boilers down to such a definite basis that new installations can be designed with a foreknowledge of exactly what results they will produce, and thus eliminate all jeopardy as to continuous operation and the investment in equipment.

As usual, the occasion finally brought forth the man. Mr. John Anderson, Chief Engineer of Power Plants, The Milwaukee Electric Railway & Light Co., had the rare foresight to realize the possibilities of the method if properly developed, and the courage to undertake the work. After several years of experimenting in one of his Company's smaller plants, he decided to equip the new Lakeside Plant for firing pulverized coal exclusively. The first section installed contained 10,450 H.P. of boilers which went into commission Dec. 15, 1920, and have been in continuous use ever since. "No difficulties have been experienced and operations have been uninterrupted up to the present time."

Thermal efficiencies fully equal to those obtainable when burning oil have been developed when burning low grade coal; and the firing equipment is as easy to control as that for the efficient firing of oil.

Probably no plant in the world has been watched more closely as to results than this one; both skepticism and disbelief were freely expressed, yet the results have proved superior to expectation and Mr. Anderson's labors have resulted in bringing the burning of pulverized coal to a demonstrated commercial success. By the end of 1922 several of the largest power plants in the United States have introduced this method on a large scale, and others are rapidly following their lead.

Few developments in power plant practise will be of as far-reaching benefit to humanity as this one because it enables industry to use with high efficiency vast quantities of low-grade coal which previously could be burned only with difficulty and low efficiency, or not at all. In the anthracite coal regions even river mud, consisting mostly of finely pulverized coal from the washers, has been dredged up and burned by this method with great success.

Caution! The number of inquiries received for information on this subject prove that there is considerable popular misapprehension about it. Many assume that all that is necessary is to remove the grates, install a spout to feed the fuel, then fire up and go ahead. Unfortunately such is not the case.

We cannot serve our clients better than to impress upon them that the proper design and installation of pulverized fuel equipment requires engineering knowledge and experience of a high order, hence *should never be entrusted to novices!* But if properly installed the operation of such equipment and the continuous maintenance of high efficiency with it are no more difficult than when burning oil.

To burn pulverized fuel successfully requires *large furnace volume*—not less than one cu. ft. per each 24,000 B. T. U. liberated in the furnace per hour when operating at maximum rating. Further, *height of furnace* is as necessary as volume. Besides these factors there are many others equally vital, such as prevention of slag, due to clinker-forming matter in the coal, from gathering on the tubes or filling the furnace. Further, the furnace should be so arranged as to impart to the boiler tubes the maximum percentage of heat by direct radiation. Fig. 58 shows how perfectly the Kidwell boiler complies with this requirement.

Proper pulverizing, and usually drying, of the coal is essential and the equipment for doing this is now unsuitable or too expensive for paying operation on a small scale. At this time (August 1922) it appears reasonably proved that, all items considered, it will not pay to install such equipment for plants developing less than 3,000 HP.

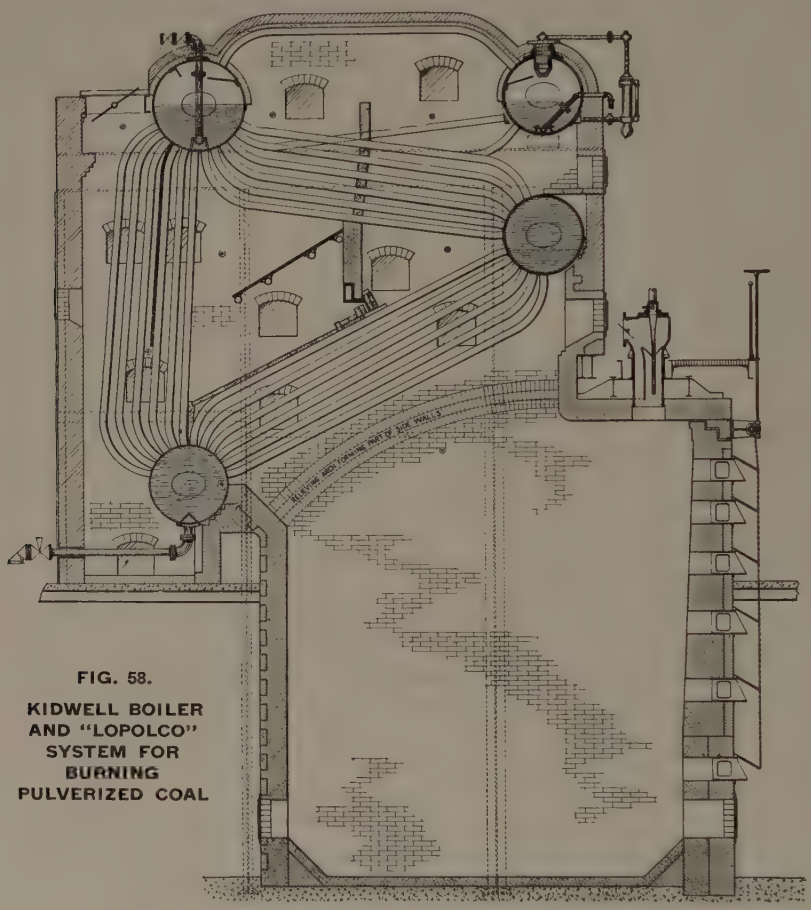


FIG. 58.

KIDWELL BOILER AND "LOPOLCO" SYSTEM FOR BURNING PULVERIZED COAL

Further, the stack requirements when burning pulverized coal are very different from those existing when other methods of firing are used. See Sect. 665.

190. General Form of Fuel Efficiency Curve. In sundry places in this book it is stated that when boilers are *stoker fired* their point of maximum *commercial efficiency* lies usually between 150% to 200% of rating, and often higher, and that frequently the maximum *fuel efficiency* also is obtained at the higher rather than the lower ratings. See Sects. 183 to 186, and 490 to 499. Yet in Fig. 4 the efficiencies decrease as the rating is increased. This discrepancy requires explanation.

191. The factors affecting fuel efficiency are so numerous that it is impossible to list them all. See Fig. 47. Yet a change in even one of them will change the efficiency. It is therefore impossible to work out any method of determining *a priori* the fuel efficiency of any boiler corresponding to every arrangement or relation of such factors. But by closely limiting the number of factors to be considered, and making some reasonable assumptions, it is possible to derive certain very general forms of curves which serve as guides to point out approximately what may be expected when other factors enter the problem.

192. This ground has been well worked over by Mr. Wm. Kent in his *Steam Boiler Economy*, 1st Edition, p. 205.

Let W = Water evaporated per hour, in lbs. from and at 212° Fah.
S = Area of heating surface in sq. ft.
K = B. T. U. per lb. of fuel as fired.
t = Degrees difference, Fah., between steam temperature and that of air entering the furnace.

unchanged, the straight line on top shows how the efficiency drops as the rating increases. This is so because while the gas quantity and velocity increase directly as the rating and therefore deliver more heat to the boiler surface, the *rate of heat absorption does not increase quite as rapidly as the gas velocity increases,* until this

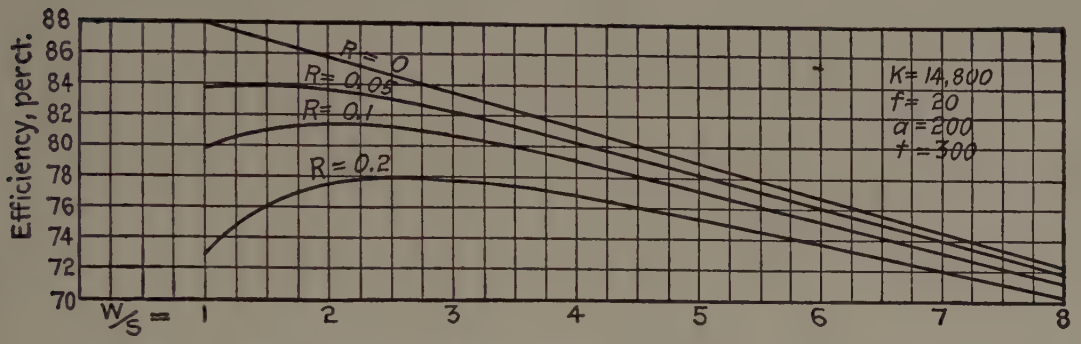


FIG. 59. KENT'S CURVES SHOWING EFFECT OF RADIATION ON FUEL EFFICIENCY

f = Weight of gas, lbs., per lb. of fuel.
a = a coefficient depending on combined effect of sundry factors not here enumerated.
R = Radiation loss through setting, expressed as a percentage of the heat taken up by W.

velocity is greater than in boilers as ordinarily set and operated. See Bulletin 18, U. S. Bureau of Mines, *The Transmission of Heat Into Steam Boilers,* p. 101. What is not shown in the above line is that as the gas velocity increases the *rate of falling of efficiency decreases,* and a point is finally reached beyond which the efficiency

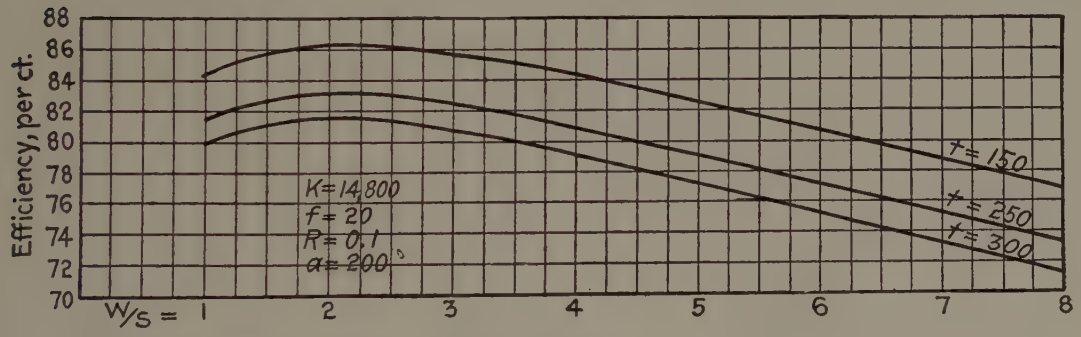


FIG. 60. SHOWING DECREASE IN FUEL EFFICIENCY WITH INCREASE OF STEAM PRESSURE

The efficiency here considered will be the total B. T. U. utilized by the boiler for production of steam divided by total B. T. U. supplied by the fuel = combined efficiency of boiler, furnace and grate, which is the correct measure of what the boiler owner gets for what he pays to keep operating. There are many other kinds of boiler efficiency which are useful to engineers and designers, but these are of little interest to boiler owners hence will not be considered here.

193. After making certain assumptions Kent derived Fig. 59. If it be assumed that R is zero, while all other factors except W remain

drops but little if any. See pp. 20 and 24 of Bulletin 18 on "True Boiler Efficiency."

194. If now radiation loss is taken into account the efficiency line becomes a curve, with a maximum at some rating varying with the amount of such loss. If the fires be banked so that only sufficient heat is produced to hold the steam pressure constant, the efficiency will be zero, yet sufficient fuel has been burned to overcome the radiation and heat the flue gas.

195. Next assume that we vary both W and t, the latter meaning that we change the steam pressure. It is evident that as the pressure in-

creases, the steam and water temperatures also increase, hence the *temperature difference* between the gas and the water must *decrease,* hence the heat absorption also decreases, so the efficiency drops. To show this, Kent developed Fig. 60.

196. Similarly, by changing one or more of the innumerable factors affecting the efficiency we could derive an infinite number of such curves, provided we understood the *exact* effect of every factor in changing the curve, which we do not as yet. Fig. 47 shows the marked effect of some factors which are seldom thought of by the average operator, yet there are many others whose effect is equally great.

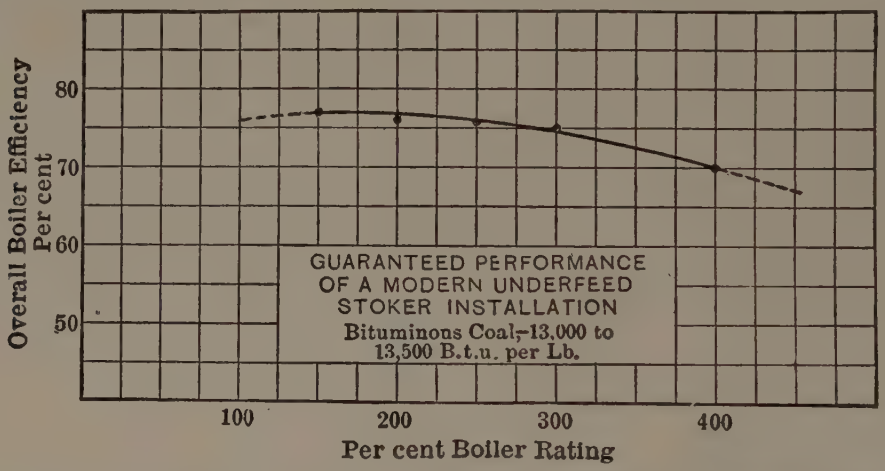


FIG. 61. SHOWING HOW HIGH EFFICIENCIES ARE POSSIBLE AT HIGH RATINGS

This simply confirms the oft repeated statement that the usual extravagant claims as to high efficiencies, without reference to the conditions to be met in each case, are merely flights of the imagination rather than expressions of technical fact. See Sect. 88.

187. Deductions from the Above Exposition. The less the radiation loss the nearer the efficiency curve will approach a straight line, and the efficiency will decrease with rating, *all other conditions remaining the same.* But in any actual case they seldom remain the same, hence the departure from a straight line is more marked, and under good operation the efficiency rises over a large range of increase in rating. Thus, in Fig. 60 suppose f decreases as the rating increases. This reduces the amount of excess air, and the maximum point in the curves moves farther to the right hand. If the percentage of CO decreases and the CO_2 increases, the same effect follows. See blocks C and E in Fig. 47. Certain other factors produce the same result.

198. Progress in Stoker Design has developed machines which produce precisely the effects above named, and thus increase the efficiency at higher ratings. Note the statement of Jacobus in Sect. 185, that "The best efficiency is reached at slightly above rating and remains constant to nearly double rating. The reason is that as the rate of combustion of the coal becomes greater the *furnace efficiency* increases to a sufficient extent to offset the loss of heat absorption efficiency of the boiler itself." Further note Azbe's statement in Sect. 495 that "Since high boiler efficiency at low ratings is more difficult to obtain than at high ratings, it follows that boilers should be installed designed for high overloads and high and constant efficiency over a considerable capacity range."

199. Boiler manufacturers' catalogs often present fuel efficiency curves said to represent average conditions, and a close scrutiny of these shows that the point of maximum efficiency is higher in proportion as such boilers have better circulation. One manufacturer of a fairly good water leg type states as to his curve that "The efficiency characteristic reaches its maximum between 100 and 150% of rating."

200. Therefore modern stokers firing boilers having rapid circulation move the point of maximum efficiency up to higher ratings than previously possible, and the limit of progress has not yet been reached. Fig. 61 from Gebhardt's *Steam Power Plant Engineering,* p. 166, shows

clearly what is possible today, therefore operating at low ratings represents a loss both in fuel and in investment.

It is clear from Figs. 59 to 61 that at a short distance beyond the maximum point these curves reduce practically to a straight line, hence the reason why the lines in Fig. 4 show a drop in efficiency as the rating increases is that with the stokers used in these tests, and the other conditions existing, the maximum point would be found at some rating lower than any at which the boilers were operated. These tests were made in 1911, at which time stoker development had not proceeded to the degree since attained; these results as compared with Fig. 61 therefore indicate the progress made during the last 12 years both as to design of stokers and in the technique of operating them.

201. "Overboilering" a Furnace. The trend in all modern power plants is to operate boilers much higher than at their nominal rating, *because that pays* as above proved, hence operating them at under ratings *certainly will not pay!* Yet regularly some scheme which is equivalent to operating boilers below rating is brought out and proclaimed as a new and wonderful means of securing economy, hence it is necessary to expose this fallacy. Refer to Fig. 175, curve A, and note that the last 20% of the heating surface absorbs only about 3% of the total heat imparted to the boiler by conduction and convection, hence adding extra *boiler surface* to extract more heat from the gas will not pay. This was proved long ago by George H. Corliss. He built a boiler of the locomotive type with extra long tubes and subjected it to sundry tests. He found that the last 4 or 5 feet of tube length not only absorbed too little heat to pay, but that unless the boiler were heavily loaded, these last few feet *actually condensed steam made in the forward part of the boiler.* In consequence, when he removed this extra length the boiler showed greater capacity and efficiency. This clearly proved the fallacy of "overboilering" a furnace.

202. Also, there will be rapid corrosion and pitting of the metal in this additional surface, because the air and carbonic acid gas entrained in the feed water, as shown in Sects. 134 and 136, gather in bubbles on this surface, hence corrosion and pitting occur. See Sect. 287. This trouble is intensified because the water in such an arrangement is at or very near the critical temperature at which the chemical action proceeds with the greatest rapidity. The only sure method of preventing such results is to extract from the feed the air and carbonic acid gas as explained in Sects. 214 and 215.

203. Further, during emergencies it may become necessary to pump in cold feed, in which case the exterior of this superfluous heating surface condenses the steam in the hot gases and causes these surfaces to sweat. Such moisture in combination with the soot and the sulphur in the gas causes rapid corrosion of the exterior surfaces, hence there will be corrosion on both the inside and outside surfaces of the tubes. Even cast iron tubes as used for economizers will suffer such deterioration if the feed is colder than 80 deg., in which case special equipment must be used. See *Indirect-Acting Economizers,* in *Power,* August 29, 1916.

204. The experience of 70 years has proved beyond question that the only efficient and safe way to utilize more of the heat from the gases than done by a good boiler operating at such ratings as have been shown to be the most economical from the standpoint of Efficiency of Capital is to use a *regular economizer,* preferably in connection with an exhaust steam feed water heater.

205. Economizers, Preheaters and Deaeration of Feed Water. These are all closely interrelated, and many inquiries for information on this subject show that a very full exposition of it is required.

206. The term "fuel economizer" has long been used to designate a closed feed heater which extracts heat from the gases after they have swept over the boiler surface. As to *fuel efficiency only,* this device is the best thus far produced for the purpose. Whether as to efficiency of Capital, Sect. 139, it will pay or not must be determined for each separate case. As a general proposition it is safe to say that in plants carrying a good average load during the working period, with economizer and boiler surfaces properly proportioned to each other, and with ample draft to operate the boiler portion at reasonably high ratings, economizers will pay, and particularly so when fuel is very expensive. Where oil or gas fuel is used economizers have a much narrower field of usefulness than with coal, but by proper designing they can often be made to pay with these fuels also.

If the load is reasonably near continuous, (i.e. as contrasted with widely intermittent service, such as might happen with a hoisting engine),

and does not fluctuate excessively, then where economizers have failed to make good as heat savers it will usually be found that *the ratio between economizer and boiler surface is wrong!* Thus, it is common to find specifications in which a demand is made that the *boiler alone* must show high fuel efficiency, and no reference is made to the economizer. See Sect. 61. Such requirement is wholly inconsistent and defeats the very purpose for which an economizer is installed. Reason:—The more heat the boiler absorbs, the less the remainder left for the economizer: *other things being equal,* the lower the exit gas temperature the better the heat absorption, hence if the highest possible fuel efficiency of *boiler only* is demanded there is no way to get it except so to proportion the boiler details that the exit gases are as cool as possible;* this may be carried to such a point that the amount of heat left for the economizer to recover is too small to pay. We have seen cases where due to this cause elaborate economizer installations not only did not pay, *but caused an actual loss as the heat they recovered did not offset their reduction in the draft!* A perfect analogy would be a compound engine so designed that the high pressure cylinder did practically all of the work so that the low cylinder would be a drag and producer of friction greater in amount than the power it develops. Further, no sane engineer would buy such engine because of a guarantee as to what the *high pressure cylinder alone can do,* but would consider only the efficiency of the complete machine.

207. It is the same with economizers and boilers. The two together represent a *compound boiler,* of which the steam generator corresponds to the high pressure engine cylinder, and the economizer the low cylinder. And in a perfectly designed compound boiler the heat absorption and action in the two members is quite different.

This must be clearly understood before undertaking any economizer problem, hence the underlying principles will be explained.

208. Sect. 132 shows that for maximum fuel economy the feed water and gas must travel in opposite directions from the point of gas exit and water entrance up to the point where the generation of steam begins; from that point to where steam is disengaged the travel should be parallel. In the first stage *all the heat absorbed* goes to increase the temperature of the water; in the second stage all heat absorbed becomes latent and generates steam. The work of the first stage can be perfectly done by an economizer, and that of the second stage by the boiler proper; further, in proportion as the work of the first stage, or heating only, is done in the boiler instead of in the economizer, *the efficiency of the combination will drop,* though the boiler efficiency alone will be increased, as stated in Sect. 127.

209. Proof:—Refer to Figs. 32 and 65. The first shows the water circuit of a boiler and the second how and where the feed enters. Obviously the entering feed mixes with the water which has just disengaged steam and is of the steam temperature, hence the feed cools the boiler water. To bring the latter back to steam temperature will require precisely as much heat as is necessary to raise the feed from its entering temperature to that of the steam. This heat can be got only by condensing some of the steam already formed, or by making the water absorb that heat directly from the gas, and the amount so absorbed is not available for generating steam. Therefore, the steam output is reduced in proportion. But, if it can be so arranged that this heat could be extracted from the waste gas and imparted to the feed *before it enters the boiler, then all heat absorbed by the boiler is available as latent heat,* so that its output of steam, hence its fuel efficiency, are greater in proportion. The economizer does this heating more efficiently than the boiler because, with the counter flow of water and gas above specified, the temperature difference between gas and water is greater than in the boiler, hence the heat transfer is more efficient. Therefore:—

210. *Just in proportion as an economizer comes nearer to heating the water to the temperature of steam in the boiler, the more efficient the heat recovery will be. This means, use less boiler surface and more economizer surface,* provided:—(1) That the boiler is so designed that it can absorb the necessary heat without steamlocking its tubes, (see Sect. 225); (2) The proportion between boiler and economizer surface is such that when the combination is

**This is far from true as to Efficiency of Capital, however. See Sect. 222 and note that the author of the paper cited states that the boiler under discussion would have "to run at 150% of rating *at least, in order to generate steam at the lowest cost.*"

operating at the maximum load wanted the economizer *will not generate any steam.* Even the latter may happen without objection *if the equipment is properly designed to permit it,* which is not true of the ordinary commercial apparatus on the market; (3) The only efficiency worthy of consideration in such an installation is the *efficiency of the combined boiler and economizer,* because to make this a maximum it is necessary to make the *efficiency of the boiler alone lower* than it should be if no economizer is installed. Otherwise expressed, the boiler does the heavy work of the combination, while the economizer finishes the process by extracting from the gas the final amount of recoverable heat, precisely as buddles, Wilfley tables and oil flotation equipment in a stamp will save the fines which otherwise would be lost, while the stamps and jigs do the heavy work and extract the coarse materials which form by far the largest proportion of the values recovered.

While the above deductions may come as a shock to many engineers who through force of habit have considered it essential to strive for the lowest possible temperature in the gases leaving the boiler, the accuracy of these deductions is beyond controversy and already some advanced thinkers have clearly realized the truth. Thus, V. Z. Caracristi says:—"The total heat transfer in economizers cannot be great unless the boiler efficiency is low and the exit gas temperature is high."—*Combustion,* August, 1922, p. 77. And C. E. Stromeyer, a most safe and reliable authority, even more clearly sets forth the facts thus:—"If an economizer is to be used, *it seems highly desirable to reverse the usual procedure of proportioning it to the boiler, and instead the boiler would have to be designed to suit the economizer."—Power,* April 24, 1923, p. 656.

211. *The above exposition means a reduction in size or number of boilers purchased, yet we stand by its correctness. This book is written to give sound engineering information,* and further, the Kidwell boiler does not for its success need or desire orders which are not based upon the arrangement of equipment most beneficial to the buyer.

212. For many decades economizers were constructed of cast iron. But boiler pressures have increased beyond the point for which cast iron is considered safe by many engineers. While there is no consensus of opinion as to where the safe dividing line is, many place the limit at 250 lbs. per sq. in., and some go below that. This has created a demand for economizers made of other material than cast iron, and various metals are now under investigation or trial, but so far the only metal which has made headway is wrought iron or steel as used for boiler tubes.

213. Economizers with Steel or Wrought Iron Tubes. With such tubing the economizer can be designed for any pressure now in use, but unless proper precautions are taken such design will fail rapidly from internal pitting and corrosion due to air and carbonic acid entrained in the feed water as set forth in Sects. 134 to 136 and external corrosion due to sweating of the tubes.

214. Deaeration of Feed Water. Sect. 135 shows the amount of air and gas contained in feed water, and how these cause corrosion and pitting. The only way to prevent such results is to extract practically all of the gas and air from the feed water before it enters the economizer. This has been done in Europe for years, but only recently in this country. Patented apparatus for doing this is now on the market, and briefly the operation is thus:—the raw water is heated to the boiling point, which of itself may expel nearly all of the gas if sufficient time is allowed, but to hasten the process a vacuum is provided over the water together with means to extract the gases when liberated. See *Removal of Gas from Boiler Water,* in *National Engineer,* August, 1920, for arrangement of apparatus showing the process. Also see *Corrosion—Apparatus to Prevent It,* in *Power,* Oct. 24, 1922, for description of actual apparatus used in some large plants.

215. McDermet, as cited below, says that it has been determined by several experimenters that if the content of air or gas in the feed be reduced to 0.2 cubic centimeters per liter (1 part in 5000 by volume) the danger of internal pitting and corrosion can be overcome. If the feed be passed through an open heater *of ample capacity* so that the water is brought up to the boiling point, and has sufficient time to yield up the gas, that may meet the requirements. "The elimination of air in boiler feed water is important. Water will dissolve about 1% of its volume of oxygen at 50 deg. Fah. At the boiling point practically all the air is driven off."—*Notes on the Open Heater,* in *Power,* October 18, 1921. (But see Stromeyer's statement in Sect. 135). Unless such deaerating is done

any economizer constructed of boiler tube material is certain to cause trouble and ultimately fail. "A most salutary lesson was taught some years ago, when the admixture of air to the boiler feed was advocated *as an improvement to the circulation!* Its injurious effect was so great that the idea very soon died out. The Boiler Committee also helped to convince engineers on this point, and in all high-class engines care is taken to keep the air out of the boiler, this being the simplest and safest plan for guarding against its corrosive action."— Stromeyer, p. 78.

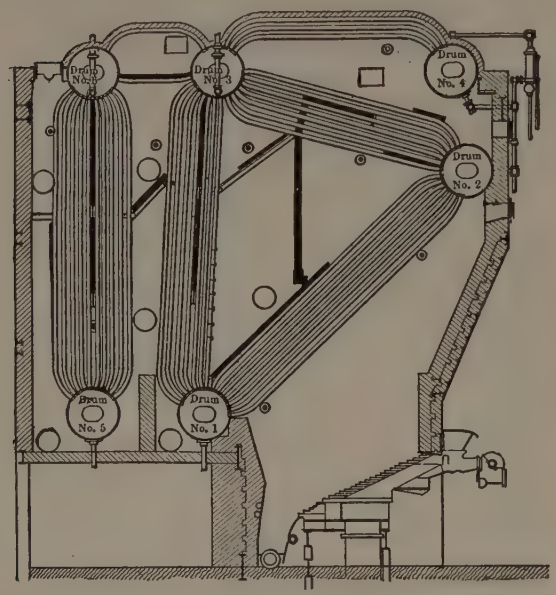


FIG. 62. A "PREHEATER" MODELED AFTER FIG 63

"The most virulent steel-feed-pipe corrosion occurs between the temperature limits 180 to 200 deg. F.; no such range is exhibited by the steel tube economizer. Water in its passage through and temperature elevation in the economizer gradually rejects a portion of its dissolved gases in the form of *bubbles which cling to the tube wall* and by coalescence establish for themselves a slower rate of travel than the water, whose velocity is materially below the region of turbulent flow. Besides materially reducing conductivity, these bubbles through their oxygen content both occasion the corrosion and distribute it over the entire surface."—J. R. McDermet, *The Interpretation of Boiler Water Analyses*, A. S. M. E. Transactions, 1921.

216. The "external corrosion, as well as a sticky clinging soot deposit will be eliminated by delivering the water to the economizer at a temperature above the dew point of the burned gases, which is not more than 120 to 130 deg. in ordinary practise. Another factor which would probably pay all of the expenses connected with the deaerating apparatus is the improved vacuum and decreased air pump operation due to elimination of air in the steam going to condensing engines or turbines."—Walter N. Flanagan, in *Modern Steel Works Power Plants*, American Iron and Steel Institute, May, 1921. If deaerating equipment is used, that automatically takes care of the feed water temperature, but in any other case we suggest that the feed should not

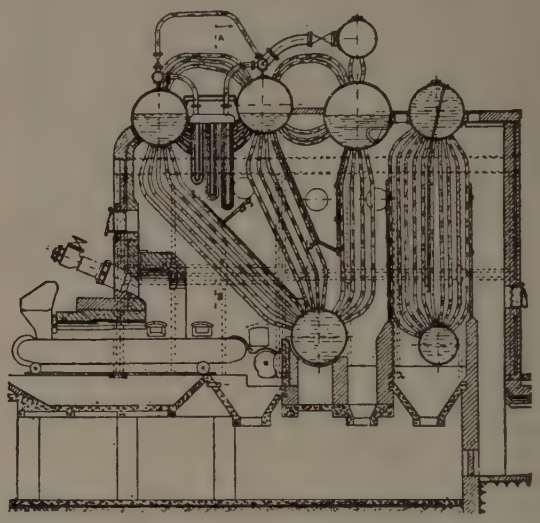


FIG. 63. GERMAN DESIGN OF ECONOMIZER WITH WROUGHT METAL TUBES

enter a steel economizer at a temperature of less than 140 to 150 degrees.

217. The method of computing the economizer surface needed in any case is too long to be given here, but it is very clearly set forth in Gebhardt's *Steam Power Plant Engineering*.

218. It is a fatal mistake to install any kind of economizer without ample draft capacity to operate at the highest load desired. See Sect. 664(g).

219. "Preheaters." The experiment of Mr. Corliss described in Sects. 201 and 202 proves the folly of providing a considerable extension of the *boiler surface* with the expectation of its acting as an economizer, and Sects. 208 and 209 confirm this. While the fallacy of this scheme has been repeatedly exposed, it springs up again and again with all the vitality and fre-

quency of the famous Hydra of mythology which grew two heads to replace each one lopped off. It appears in sundry shapes and forms as shown by U. S. Patent No. 911,685 to F. S. Snyder, Feb. 9, 1909, and by Fig. 62, the arrangement of which was probably inspired by that in Fig. 63 for which we are indebted to Harrison Safety Boiler Works, and which shows a steel tube economizer tried out in Germany. We have discussed Fig. 63 with its designer who stated that when untreated feed water was used corrosion and pitting developed to such extent that deaeration had to be resorted to. This design then did satisfactory work, as it is a true economizer and has no steam space over the water.

220. While the above facts are realized by properly qualified boiler designers they are either unknown to or ignored by many who of recent years have advocated the installation of sundry annexes to boilers, consisting of additional tube banks terminating at the top in a drum with a steam space above the water. Figs. 62 and 127 are typical examples, and such arrangements are often called "Preheaters" or "Integral Economizers" because installed as part of the regular boiler setting.

221. This Company advises against all such devices, and refuses to bid upon them for the following reasons:—(1) They merely duplicate the experiment of Corliss above described and revive the scheme of overboilering a furnace; (2) As heat savers their action is far less efficient than that of a true economizer, as shown in Sects. 208 and 209. (3) They condense steam made in the forward part of the boiler, but are not so arranged that as live steam heaters their action is efficient; (4) Unless fed with deaerated water they rapidly pit, corrode and fail; (5) Unless fed with water of a temperature of 140 deg. or higher they corrode rapidly on the outside. For this and the reason given in (4) several such installations have proved failures and had to be renewed; (6) Under no circumstances can they reduce the exit gas temperature to less than that of the steam, while an economizer can go below that limit. When the gas temperature at the preheater damper approximates that of the steam, the best absorption in the rear part of the heating surface is too trivial to pay, as below shown.

222. Buyers should therefore use extra diligence in scrutinizing each and every design which may prove to be this scheme in some new shape, because it is constantly reappearing in some new form and sponsored by men who either do or should know better. Example:—*Boiler Furnace Design,* by D. S. Jacobus, in *Power,* May 10, 1921, says:—"In designing a boiler for use without an economizer, additional efficiency may be secured by adding to its height. Increasing it from, say 14 to 20 tubes high will result in a considerable increase in efficiency." This is the Corliss experiment all over again, and the results will be the same. This has been fully proved and the evidence is unassailable. See Figs. 35 and 36 and Sect. 75 which gives information as to this design and where a full record of the tests is to be found; also see line D in Fig. 4. Fig. 35 shows a design gotten out for the specific purpose of proving the scheme above suggested, yet line D certainly does not show up anything remarkable as to efficiency even though this boiler was thoroughly lagged outside with heat insulator, equipped with a splendid stoker, and fired with excellent coal. And of the efficiencies shown by line D an average of all tests shows that 2.93% is due to the superheater, and not to the boiler. The resulting efficiencies are no higher than have been got by careful *hand firing* of a boiler without external heat insulation.

From point 40 in Fig. 35 to point 60 may be assumed as equal to about 35% of the total heating surface. A mean of 40 tests showed the following:—

Average per cent of rating developed. 76.37
Average temperature of feed,.....139.77 Deg.
At point 40, average gas temperature 404.00 "
At point 60, average gas temperature 379.00 "

Difference between points 40 and 60, 35.00 Deg.

Under the conditions existing this 35 degrees drop in temperature would produce a savings of just 2.27% due to the last 35% of boiler surface! Clearly such trivial saving falls far short of adequate return on the investment. "At the low boiler ratings the last pass of the boiler, *and in fact the last two passes,* are of very little use. The best combined efficiencies were obtained when running between 56% and 60% of boiler rating. At these low ratings the drop in gas temperature through the second and third passes altogether is about 20 deg. Fah. and the heat absorbed is very small, about 1.3% of the total. These two passes have 50% of the boiler heating surface. If the second and third passes were dropped off entirely, the loss in combined efficiency would be about 1% at the low rating. It is only when the boiler has reached 75%

rating or more that the gain in economy in the last two passes is sufficient to give a reasonable return upon the investment in heating surface. While the exit gas temperatures were reduced almost to the lowest theoretical limit which can be reached without the use of an economizer, *it was done at a large expenditure in heating surface.*"

Regarding the statement that operating at 75% of rating, or more, is necessary to make this arrangement pay, the highest rating developed during the 40 tests was 127.7%, during which the temperature at point 40 was 491 deg. and at point 60 it was 423 deg.; difference 68 deg. This represents a saving of only 4.4% over what would have been got had this last 35% of heating surface been omitted, and it is doubtful whether by any method of figuring it could be proved to pay. If an attempt is made to run at higher ratings the following will apply.

223. As showing the difference between the return on money invested in such excess heating surface and in a boiler perfectly proportioned, note that the Kidwell boiler delivers *superheated steam,* and this feature alone insures a saving beyond anything possible from such excess heating surface installed as part of the boiler. See Sects. 91 to 99, and 520.

224. The experiments above discussed confirm the finding of Corliss that the heating surface near the end of the gas pass often *transmits heat from the boiler back to the gas again! At times the gas temperature at the damper was higher than at point 60, and it even happened that at point 60 the temperature was not infrequently higher than at point 50!* This proves that heat from the boiler was being transmitted back to the gas again!

255. The suggestion above advanced by Jacobus referred to header types of boilers. Reference to Figs. 31 to 34 and Sects. 73 to 77 and 249 will reveal another weakness in the scheme, namely, the inability of such boilers of the standard heights to operate at high ratings without steam locking and burning tubes. Adding extra tubes to the height is useless as a heat saving device, as shown above, unless the boiler be fired hard enough to cause a heat saving worth while. This is recognized by the author of the above quoted tests, who says:—"With the usual prices of coal, *and interest and depreciation taken into account,* this boiler would need to run at 150% of rating *at least,* in order to generate steam at the lowest cost." But, if so run, the lower tubes will overheat and burn out just that much faster.

226. The facts as above presented fully prove that preheating schemes of the kind above discussed are futile, and that sound engineering dictates the use of either a true economizer with closed water circuit, or none at all. It may be made of wrought metal or cast iron tubing according to whether the feed water is deaerated or not. In cases where the use of wrought metal economizers is proper and advisable KIDWELL BOILER CO. is prepared to submit proposals covering designs embodying every feature of proved excellence.

227. Heating Surface Alone is not a True Measure of Either Capacity or Efficiency. This was touched upon in Sect. 39, but the explanation of circulation which followed proved it. A boiler with accelerated circulation not only develops higher fuel efficiencies, but it can with entire safety be operated for long runs, or permanently, at a rating which would burn up boilers having strangled circulation. See Sects. 249 to 255. The matter is thus summed up by Prof. Robertson in his *Water Tube Boilers,* p. 66:—"The quantity of water a boiler will evaporate is not directly dependent on (i. e., proportional to) the amount of its heating surface." That the same is true as to efficiency is thus stated by Breckenridge, p. 310 of Bulletin 23, Bureau of Mines:—"It is not the *amount* of heating surface which determines the efficiency of a boiler, but the cross sectional area of the gas passage and the arrangement of the surface with respect to the flow of gas."

"The mere piling up of heating surface in order to create a unit of large capacity answers no real economic need. The real requirement is to take existing practise and secure therefrom larger evaporative returns."—*Recent Boiler Developments,* in *Combustion,* August, 1922. Also see editorial on *Boiler Heating Surface* in *Power,* Nov. 14, 1922 for a clear exposition of this subject.

From this fact several important consequences follows:—

(a) The amount of heating surface in a boiler cannot alone be taken as a measure of its capacity or efficiency, any more than the size of a man's head can be taken as a measure of his intellect, hence the statement, "I am buying so much heating surface and not horse power"

means nothing, any more than the statement that "I am buying so many acres of land" gives any measure of the crop to be got from it when the character of the soil is unknown. The way the heating surface is arranged with respect to the furnace and gas streams, and speed of the water over this surface are the elements that count. Prof. Lucke points this out as follows:—"In two different boilers the rate of increase of (heat) absorption may or may not bear the same relation to the rate of increase in generation; it is quite possible for them to be similar in this respect, but at a given rate of generation in each it is more likely that *the actual rates of absorption should differ by reason of the difference in structure. This latter difference should require a different surface per HP. for the same amount of heat generated."—Engineering Thermodynamics,* p. 778. This is recognized in Europe and the general custom there is to specify the *amount of steam to be generated* and the conditions under which that is to be done, then leave it to the boiler manufacturer to determine how much heating surface *in his design of boiler* is required to produce that output, and bind him to fulfill his agreement. *Any other method penalizes good boiler designs and puts a specific premium on bad ones!*

(b) It is a current practise with many engineers and particularly with architects, who naturally have not the time necessary to perfect themselves on the intricate details of so vast a subject as boiler engineering, to issue voluminous specifications duplicating page after page of the A. S. M. E. or other codes, which procedure is worse than useless because the desired result can better be got by specifying that "the boilers shall conform to ——— Code." Besides wasting time of all concerned such lengthy specifications prescribe not only the results desired, frequently in a contradictory way, but fix the *amount and kind of heating surface to be furnished to obtain them,* and such requirements almost invariably conflict! This is as reasonable as for a client to specify the details of a palace and then fix the dimensions and cost so that the scheme cannot be carried out. Some specifications even go farther and try to tell the boiler manufacturer *how to design his boiler,* and if he complies the result is a weird botch.

As a general proposition, the longer and more intricate a purchaser's specification is, and the more it tries to dictate such technical details as are understood by only a very few qualified designers, *the greater the amount of trouble caused to both purchaser and seller, the larger the amount of money the purchaser will pay for things he does not need and better not have, and the less efficient the equipment the purchaser will get!* The proper procedure is for the purchaser to state the *results he wants to obtain, and the general character of design he wishes to buy,* then leave details to the boiler builder, and finally make a thorough study of the propositions as received, and *discuss details as applying to each particular proposition so that he knows exactly what that proposition covers.*

As evidencing the correctness of this course we cite:—(1) We have seen specifications so written that compliance with them would insure a plant not only 25 years out of date and foredoomed to failure, but costing at least 35% more than a high grade modern installation. Leading boiler manufacturers of course refused to bid on such installation. (2) Many large interests who purchase boilers frequently and in quantities issue specifications seldom exceeding two letter pages in length.

(c) Since boilers are purchased to earn money, the buyer should consider, not what a boiler will do at some irrelevant rating, but at the rating at which he intends to run it, and particularly the *highest rating likely to be needed,* since that is the point where most boilers are likely to fail. See Sects. 109 to 112, also Figs. 4 and 5.

(d) While every boiler purchase should be accompanied with a complete, clear and definite specification, it is the *seller of the boiler who should present it,* and thus reverse the usual procedure. And the said specification should form part of *a contract,* therefore be so written as to embody every point which has been agreed upon in conference between purchaser and seller, and *eliminate any possible ambiguity as to exactly what the purchaser is to get, what it will do, and what both parties to the contract are to do!*

(e) Anything less than that fails to protect the purchaser and will result in acrimonious debate and usually a deficient installation. Therefore unless a purchaser carefully checks the final specification item by item he is simply "buying a pig in a poke" and will have no one to blame but himself.

We have forcibly stated the facts because only those who have had long experience in these

matters can imagine the extent to which boiler buyers content themselves with *superficially glancing through a specification,* without any attempt to check it carefully, and then purchase on *price only,* with the inevitable result of making a poor investment.

(f) As the purpose of this book is to present those facts pertinent to the interest of buyers, it is not out of place here to say that the above tendency to *skim through a specification instead of checking it* is well realized by sellers, hence anyone who wishes to take advantage of it to the detriment of the buyer may easily do so by presenting a "the less said the better" specification, with the purpose of letting the purchaser find out later that all omissions were made at *his expense and not that of the seller.* In this connection read Sects. 581 to 593 and particularly note the case cited in Sect. 583.

The inflexible policy of KIDWELL BOILER COMPANY is to inform its clients what it proposes to do, and what it expects them to do. Therefore, not only are its boiler specifications the most complete that have ever been written, but attached to them is an instruction sheet which urges clients to check the specification carefully, and summarizes the main points they should consider. A blank copy of these specifications will on request be mailed to anyone who has a legitimate reason for asking for it.

A Spark from the Furnace. No. 2

Through the courtesy of *The Associated Newspapers,* New York, we are enabled to reprint the following pertinent article:

Running on Schedule

By John Blake

If you had your choice of two parallel railroads in going to a particular city, which one would you take—the road whose trains run on schedule or the road whose trains were invariably from fifteen minutes to three-quarters of an hour late?

Twenty or thirty years ago, when there were not so many continental lines, one railroad manager got 75 per cent of the passenger business by getting all his trains through on time—save when landslides or blizzards prevented.

The management of the other road awakened too late to what was going on. The tide of travel had gone the other way, merely because one man knew the value of running on schedule, and it was not brought back for many years.

Your value to anybody, whether it is to the boss or to the public, or to your friend, *is a matter of dependability. Dependability is a matter of being there when people expect you to be there.* If you are working in a big institution you soon discover that you must be there on time, or not be there at all.

It is just as necessary to be punctual with the discharge of your work as it is to be in the office at the hour when work begins. If you are late with a particular job, the man to whom you must pass it is late starting it, and unless someone hurries and slights the task along the line, the schedule may not be restored for the rest of the day.

The man who keeps his engagements and keeps them on time, the man who can always be counted on to arrive when he ought to arrive, is the man who is trusted by business associates and who gets business in consequence.

It is quite possible for the early bird to be there before the worm is out of bed. It is the bird who knows just exactly at what hour after sunrise the worm gets up and who is there looking for him at that exact hour who is always sure of his breakfast. Be early if you want to, but far more than important to be early is to be on schedule—always.

As with persons, so with Boilers! Dependability is the most important requisite of Both. See Sect. 25(i). The Kidwell Boiler fully meets this requirement, as shown in Chap. VI. See Sect. 471 for a pertinent comparison of railway and boiler practise.

III. A Few Applications of the Preceding Principles

228. We purpose here to discuss only those facts whose understanding is necessary to enable one to judge whether or not a boiler design is deficient in the particulars which we have already shown are essential for meeting present day requirements. A careful purchaser should check up every design item by item per Sects. 381 to 385, but for brevity we shall here discuss only a sufficient number of designs to show how others may be similarly dissected.

229. The preceding exposition has proved the inadequacy of all header designs as to speed of water circulation and certain other details, and the following will merely intensify that proof.

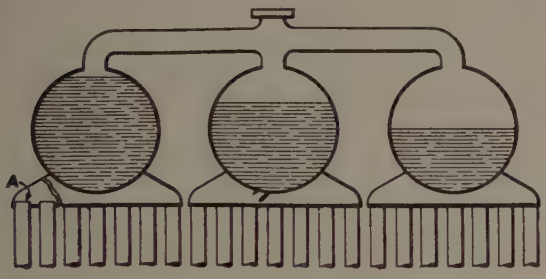


FIG. 64. PROVING VARIATION OF WATER LINE IN PARALLEL DRUMS

230. That a difference of water level between the front and rear ends of longitudinal drums is unavoidable is proved in Sects. 58 to 65. But when several such parallel drums are used a *further difference in each drum* results as in Fig. 64, due to variation in the intensity of the fire across the furnace width. If a feed water regulator were attached to the right hand drum, this might start to feed when the left hand drum is full, and thus cause water to be pulled out into the steam main. See *Difference in Water Levels in Boilers,* in *Power,* Feb. 11, 1919.

231. Uneven Concentration of Boiler Water. Another deficiency of all header types with parallel longitudinal drums as in Fig. 64 is that the feed pipe is branched with a connection to each drum, and it appears impracticable, if not impossible, to make such branches feed evenly. In consequence, there are really as many *separate parallel boilers* as there are drums, and this is particularly so of sinuous header types like Fig. 30 in which the only way that a deficiency in the water supply in any drum can be made up is by a flow from the other drum or drums, down through the mud drum, and up into the top drum whose supply is short. If the water is bad it may during this process become highly concentrated and cause frequent tube losses in the section whose water supply is deficient. For typical cases of this kind see *Boiler Tubes Burned Out,* in *Power,* Nov. 25, 1919, and *Tube Burnouts in Water Tube Boilers,* in *Power Plant Engineering,* Oct. 1920. Also see Sect. 138.

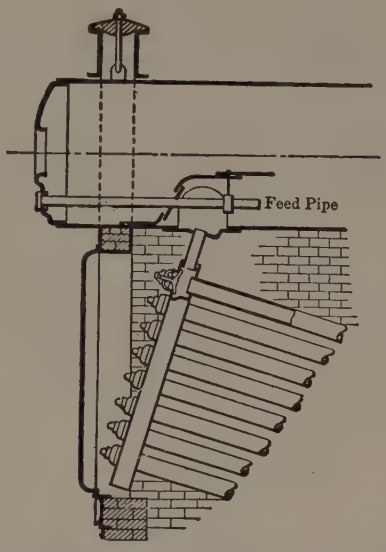


FIG. 65. BAFFLE TO REDUCE SPOUTING FROM NIPPLE

232. Header and Nipple Types with Longitudinal Drums are fed as in Fig. 65. This does not comply with the law of efficiency given in Sect. 132, and further, the water circuit from point of feed entrance until it reaches the tubes is *increasing its speed,* which is just opposite of what it should do, as shown in Sect. 133. The precipitates are therefore swept into the tubes, (Sects. 119 to 122), and the mud drum is not in the water circuit hence is of little effect. Herein lies one reason for excessive tube failures. Still other important ones are shown in Sects. 148 to 151, and 249 to 256.

233. Since every feature which obstructs the free flow of water is a detriment as to capacity, efficiency and durability, the construction shown

in Figs. 10, 37 and 45 is clearly objectionable. With this it was not uncommon to find, when dirty feed water was used, a formation like a

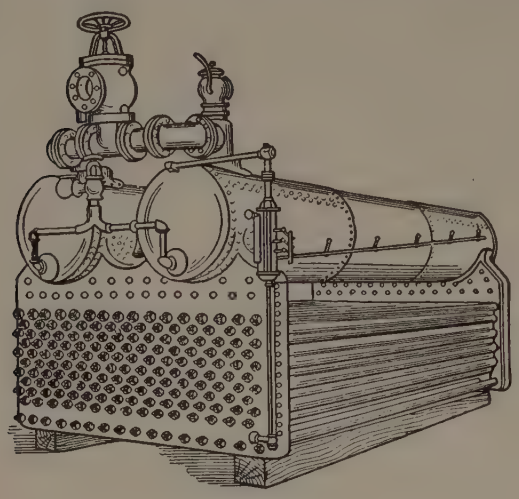


FIG. 66. A WATER LEG BOILER

mud dauber's nest plastered on top of the drum over the up-comer. This water spouting produces priming, therefore to prevent it a baffle the water line where its resistance is less. Other schemes to prevent spouting are explained in Sects 267 to 272.

As shown in Sects. 145, 249, 257 to 271 and particularly in Sect. 471, these nipples are inadequate when boilers are to be operated at high ratings. But this original deficiency is often greatly increased because these constricted passages become choked with scale, hence reduced in area, and thus make a bad matter worse as shown by Kent in Sect. 115 and McHugh in Sect. 145. Here read footnote to Sect. 471.

234. In the development of marine boilers where economy of space and weight are essential, header types have gradually evolved into a curtailed design with a single cross drum as shown in Fig. 68 from *Engineering of Power Plants* by Fernald and Orrok. As this *economizes on cost because of the reduction in drum capacity,* some astute salesman saw a chance to develop trade by urging it for stationary plants, and its use for such purpose is increasing, not only because of the reduced price at which this construction is offered, but because of energetic sales propaganda directed toward finding for it a market to replace that lost since the use

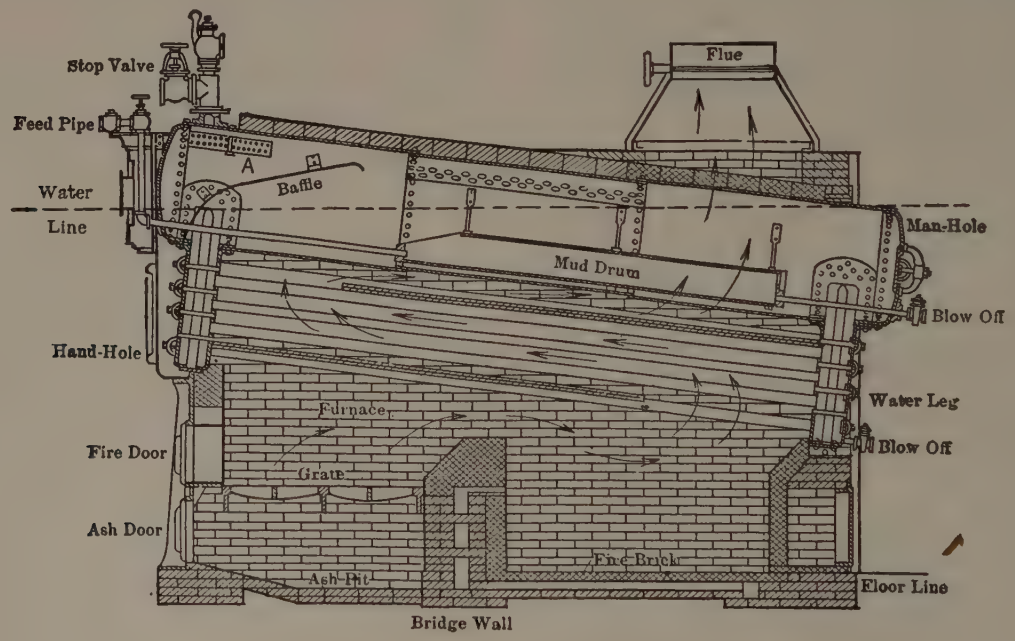


FIG. 67. LONGITUDINAL SECTION THROUGH FIG. 66

as in Fig. 65 is now used, but this further obstructs the flow, which is detrimental. Fig. 67 from Gebhardt's *Power Plant Engineering* shows a better arrangement as the baffle is placed above

of this design for Naval installations has practically ceased, as stated in Sect. 154. Even a casual analysis will show, however, that *this is an unfortunate step backward!*

235. The reasons for this follow:—

(*a*) It greatly reduces the water endurance surface (Sect. 78) which largely decreases its ruggedness in operation, therefore its safety, which has lead to some serious accidents.

(*b*) Its steam space is similarly reduced, which proportionately increases the intensity of endurance with serious results if anything goes wrong, as unfortunately illustrated in "Cause of the *San Diego Explosion*" in *Power*, Mar. 30, 1915, p. 456, details of which are given below. Also, inspection of Fig. 68 reveals that the average distance through the tubes over the fire from the drum is *less by way of the rear header*

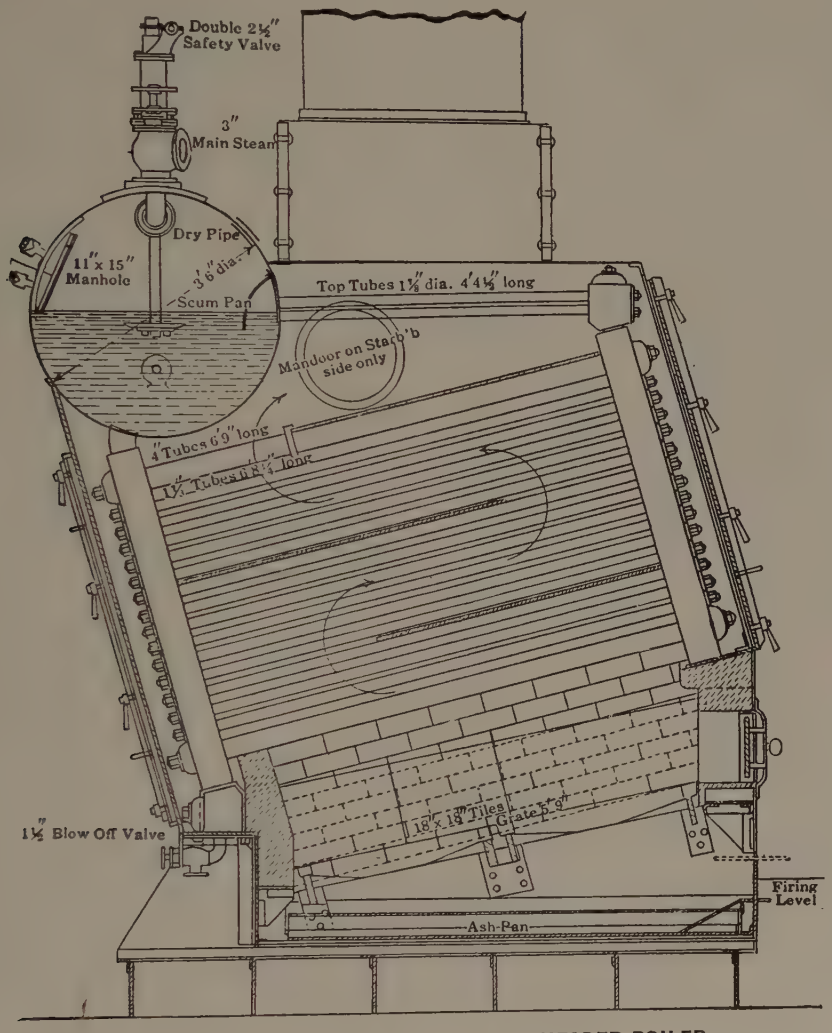


FIG. 68. CROSS DRUM MARINE TYPE HEADER BOILER

the "pop-bottle" action (Sects. 85 to 88) and priming when the pressure suddenly drops. If the feed water is dirty such action causes the boiler to vomit mud into the mains to an extent which is extremely serious in cases where the steam is used in processes, such as in digesters for pulp. To reduce such priming and mud vomiting, the water has to be carried very low when the load is heavy. But this cuts down the water

than by way of the front header and over-comer tubes, hence when there is a sudden evolution of steam due to drop of pressure in the drum as explained in Sects. 85 to 86, this will take the path of least resistance, *hence reverse the flow*, and be ejected into the drum like a geyser through the down-comer nipple. This greatly increases the liability of priming, hence the necessity of carrying the water low when operating

at reasonably high ratings as shown in the *San Diego* explosion above cited. "As the water was *being carried rather low and the engines running at full power,* it was impossible to get sufficient water to all the boilers, with the result that 5 boilers were badly overheated when the explosion occurred." This water shortage was due to a strainer dropping on and partly closing the suction pipe to feed pump, and so small was the water endurance surface of the boilers that they failed before this trouble could be remedied. A defective pump valve or similar item is not unusual in any plant, but with such limited water endurance surface in the boilers such occurence places the boilers and human life in jeopardy.

(*c*) The additional resistance of the top tubes connecting front header and drum still further reduces the speed of water circulation. The constricted area of these tubes is such that if free to do so they would eject a stream clear across the drum, as in Fig. 76. To prevent this a baffle is inserted as in Figs. 68 and 77, and this further increases the resistance, from which it is clear that this type cannot operate at high ratings without steam locking its tubes. Make a flow diagram like Figs. 33 and 34, of the designs in Figs. 68 and 77, and the proof of this statement will become evident. It will also show the reason for the statement in *Marine Steam,* First Edition, p. 127, to the effect that tubes often fail because of overheating where a piece of scale has been *swept along by the circulation and dropped in the tube. It drops there for the reason that the water speed is least there,* instead of greatest as it should be, as proved in Sect. 52.

(*d*) This design is often provided with a steel casing which is frequently urged for other types also, yet such casing, unless caution be used, may *decrease the efficiency instead of increasing it,* and make the boiler room hotter than when a brick setting is used. This was clearly proved by numerous experiments by the U. S. Bureau of Mines described on p. 298, Bulletin 23, *Steaming Tests of Coals,* and further explained in Sects. 388 and 389.

(*e*) The liability of plugging the down-comer nipples with scale is even much greater than is the case with longitudinal drum boilers, as shown in Sect. 115.

(*f*) It follows that the disadvantages of this general design are out of all proportion to its sole advantage of cheapening the cost of manufacture by reducing the number of drums, hence buyers should carefully weigh all these points before selecting boilers of this kind.

This caution is particularly necessary because many builders have during recent years taken up this general design *by reason of its low cost of construction,* and are active in exploiting it. Further, the U. S. Emergency Fleet Corporation produced a design of this sort which was called the "E. F. C. Standard Boiler," and large numbers of these and others of nearly identical design were built. Later many of these were sold at sacrifice prices to clear them out and speculators who purchased these are actively seeking a retail market for them. Buyers should therefore exercise considerable caution and investigate thoroughly before purchasing such material because offered at a low price. Not a few who failed to do this have found ample reason to regret having accepted what they first imagined was an attractive bargain. Where wet steam is troublesome or the feed water is dirty and mud is carried out with the steam, some extremely disappointing experiences have resulted. Further, because of deficient furnace volume and height installations of stokers under these boilers have proved unsatisfactory in every case we have seen.

236. It is interesting to note some attempts made to explain away or palliate the incurable propensity of this arrangement to prime and vomit mud. For example, see *Steam,* page 71, second main paragraph, and note how the writer states that as the result of numerous experiments during the development of the longitudinal drum boiler certain steam and water space proportions *have been found essential.* Then refer to last paragraph on same page and note that when discussing the design as shown in Fig. 68 he says that such proportions are *not essential, and that greatly reduced ones are entirely satisfactory!* The reader must decide which statement to accept. See Fig. 135C, page 146.

In view of the numerous deficiencies of this general design it was inevitable that some who had been induced to purchase it soon found cause to regret their choice, and sought relief from its troubles. KIDWELL BOILER CO. has on several occasions been urged to help out by suggesting some reconstruction which would improve the action. In every such case our reply, after making the proper survey, has been that while by certain alterations an improvement in action could be secured, *the main deficiencies are inherent to the general design, hence incur-*

able. The expense of the possible alterations would form so large a proportion of the cost of a new and properly designed boiler that reconstruction could not be recommended. The owner had therefore to choose between bearing with his troubles or replacing the defective designs with something better, and where dry and *clean* steam was essential for processes the latter course was the one followed.

To assist the reader in reaching a correct conclusion the following facts may prove useful.

While boilers of the general design just discussed have been frequently purchased of late years and it now seems fashionable with some engineers to recommend them, the preceding analysis nevertheless clearly indicates that this design is not only deficient, but extremely so. The reader will naturally ask why, under such circumstances, this design finds purchasers, and our reply is:—(a) Because it is offered at a lower price than necessarily asked for better designs which require the use of several drums, and there are always some who buy solely on first cost without consideration of what the equipment will do (see Sect. 583); (b) Because of shrewd and active sales propaganda based largely on *the claim that the government has put its stamp of approval on this general form because it was during stress of war conditions largely used for the principal reason that any ordinary shop could build it!* With those who are unwilling to do their own investigating such an argument is often sufficient (see Sect. 277); (c) Principally because the deficiencies revealed in our analysis are entirely unknown to all but the few engineers whose experiences with this design have caused them to study out its action and realize its weaknesses.

But to check our conclusions we have carefully compared them with what we find in actual installations, with the following results.

Some "Emergency Fleet Corporation boilers" were set up in a paper mill. The water in the glass surged so erratically and through so wide a range that it was impossible for the operator to judge with any accuracy as to the location of the water line inside the drum. The boilers primed so violently and carried over so much water and mud into the digesters that the pulp was so discolored as to be of inferior quality and at times unsalable. It was impossible to develop any reasonably high rating without intensifying these troubles to a degree that could not be tolerated. The capacity of the plant was thus so reduced that this, in connection with the poor grade of pulp produced, resulted in shutting down the mill until new boilers could be installed.

In another plant containing water leg boilers of this general design precisely the same result occurred as to surging of the water, priming, and carrying over mud, and while for one year diligent attempts have been made to improve the action these have proved futile up to the time this account was written. See top of page 146.

In another installation of the same type of boiler at a point several hundred miles from the one just mentioned, identical results occurred, and we were asked to suggest means of overcoming the troubles, but were unable to do so.

In April, 1923, tenders were invited on some 1100 HP. units including a guarantee as to the quality of steam delivered, and among the bids there were two from manufacturers of sinuous header boilers of the general design herein discussed. One of these stated that the steam would be *commercially dry* (see Sect. 89), while the other one stated the steam would contain 2% of moisture at the entrance of the superheater. This means that because of dirt carried over with the wet steam the superheater tubes will surely become encrusted with deposit, drop off in efficiency, and finally overheat and burn out.

We have discussed the action of this design with many who have had extensive experience with it both on land and at sea. A few report that if the installation is hand fired and operated at not to exceed from rating to 25% above rating and fed with only the best quality of feed water, it will operate with fair satisfaction. But without one exception the reports have been that if stoker fired or operated at the high ratings now known to be essential for highest efficiency of Capital (Sect. 106), its water line is erratic, its priming is excessive, and that the only way in which operating can be kept up is to carry the water down to the bottom of the glass, just as indicated in the *San Diego* disaster above discussed. *All the above will occur with the best of feed water,* but if the feed happens to contain even an amount of impurities which other boilers of proper design can handle without difficulty, this one will not only develop the above described troubles to a greatly increased degree, but will carry over mud in excessive quantities as above shown in the reference to a paper mill,

encrust the superheater tubes, and burn out boiler tubes over the fire to a degree which renders it a most expensive menace to both efficiency of Capital and safety of the operator. Compare this with Sects. 532 and 653.

237. Why Caps Using soft Gaskets Leak. With soft gaskets it is practically impossible to keep handhole joints always tight. The reason is that though tightened up when cold, they leak when hot because the holding bolt expands, hence after the boiler is hot it is necessary to go all over these caps and tighten up the bolts once more! But, if the boiler is then shut down for any cause these bolts cool and contract again, thus smash down the packing until it is thinner, so when the boiler is once more fired up the joints will leak anew unless the bolts are all tightened up again! As illuminating this subject, read *Boiler Water Leg Drip Pan in Power,* June 1, 1920. For this reason it is very unusual to find any boiler with handholes so packed that it does not leak, and apart from the heat thus lost these leaks cause corrosion to such degree that we have seen cases where *the tube sheets had to be renewed from this cause!* Such leaks account for the presence of the festoons of scale referred to in Sects. 146 and 551, though these are also frequent in boilers with caps bearing metal to metal.

238. To obviate this nuisance from soft packings lead gaskets are often used, but these must be recast after every removal. This is expensive as we have noted that where 4000 HP. of boilers so packed were in use, *two men were kept busy all the time moulding and fitting lead gaskets.* Also gasket renewals at each cleaning involve considerable expense.

239. Before closing up the boiler it is necessary to go over every joint carefully and see that the parts are in good condition, yet even with this precaution it is the rare exception when there is no leak after pressure is applied. Such leaks usually require stopping, letting down of the water, removal and further preparation of the caps and seats, and the expense of all this mounts up to a total seldom realized. See Sect. 551.

In fact, closing up is a much more trying job than opening the boiler, as explained in Sect. 146. This shows that opening and closing *any* handhole and cap type of boiler is a tedious and expensive undertaking, and it thoroughly disposes of the overworked claim that cleaning such a boiler is an easy job. In consequence, boilers using handholes and caps are usually not cleaned as often and as thoroughly as they should be unless there is an extra investment in spare boiler capacity which otherwise would not be needed, and a lot of extra help provided which otherwise would be unnecessary. Plant operators very frankly confess that they have no time to open and handle all these parts, *hence clean only the lower tubes regularly,* and a few of the others at intervals as they find the time available. See Sects. 143, 251 and 252.

240. Why Mud Drum Nipples Leak When Blowing Off. Observe in Figs. 30, 35, 68, and 76 that the mud drum and nipples are out of the path of the circulation, therefore the water in them is cooler than in the main circuit. If blowing off is attempted this cold water is quickly ejected, and hot water rushing in suddenly so expands the parts that leaks result. When cast iron mud drums are used as in Fig. 30 this sudden expansion may produce a rupture, and serious accidents have been thus caused. See *Fatal Boiler Explosion at Seattle* in *Power,* March 16, 1920.

241. Rupture of Sinuous Headers Caused by Packing Between Them. In boilers having headers like Figs. 18 to 30 there will be leakage of air through the spaces between the headers unless these are plugged up tight. While this may stop the air it introduces another trouble which may cause disaster, as shown in the following quotation from *Power,* Jan. 18, 1921, p. 115:—"Another thing that an engineer should watch is the asbestos packing between the headers of some types of water tube boilers, * * * which in time becomes extremely hard. A case recently came to the attention of the inspector in which it was necessary to use a cold chisel to remove the packing, which seemed to be as hard as flint. It is easily seen that under such a condition there is no opportunity for the headers to expand with the heat, and as a result, *quite a number have been found with cracks between the tube holes,* as shown in Fig. 69. It is assumed that the solid condition of the asbestos was the cause. The remedy is, of course, to remove the packing as soon as it begins to harden."

If security against rupture of the header depends upon the vigilance of the operator in keeping watch to see when the asbestos is getting hard and of then removing and replacing it, the probability of such renewal being made on time is

small. In connection with this note the number of headers recorded as having failed, in the list of explosions cited at the end of Sect. 249.

242. Corrosion Between Headers is not infrequent, and it cannot be seen until the metal walls are eaten through, nor can it be repaired without replacing a header, which is a long, tedious and expensive job. The time such boiler is out of commission pending the arrival of such header is a serious item.

For a typical case of this kind see *The Boiler Maker,* August, 1915, p. 258, showing how a header failed in this way on one of our Naval

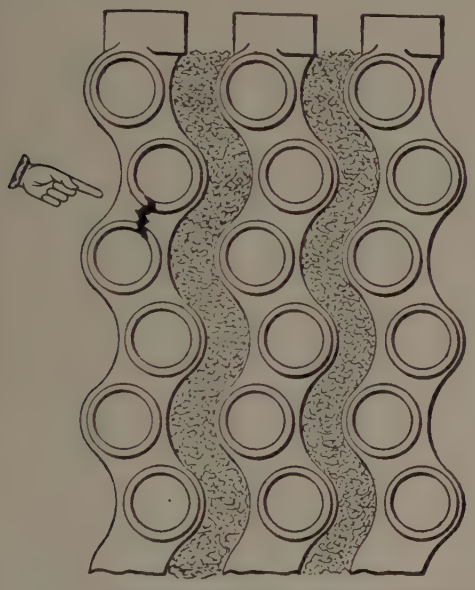


FIG. 69. SHOWING SINUOUS HEADERS RUPTURED BY PACKING BETWEEN THEM

vessels, and the difficulty and expense of patching up the boiler sufficiently to steam to port. Fig. 198 and Sect. 568 show the header which failed in this case.

Nor is this all. When the corrosion between headers occurs and iron oxide is formed this material is of so much greater volume than the iron from which it was formed that *it actually forces the headers apart,* just as wet beans or peas will force open and rupture a barrel.

All the above will be illuminating to those who consider that any design involving such a multitude of parts subject to so many troubles is either a good one, or easy to repair.

243. Secondary Stresses in Nipples. A weight X, Fig. 70, will produce in a vertical suspending rod only a tension. But a weight W will produce a bending stress at Y in a rod at an angle with the vertical. This is more difficult to resist than mere tension. But the latter is the method of suspension used in Figs. 30, 35 and 68, and all the weight of tubes and header below, and water in them, hangs on the nipple and tends to wrench it loose. The vibration always present when a boiler is steaming aggravates that trouble, and this explains why such nipples so frequently leak. See last paragraph, Sect. 145.

This wrenching stress on the nipples is aggravated by the expansion of the tubes. When the boiler is started up and before circulation begins, the bottom tubes heat before the top ones do, hence are put into compression while those above

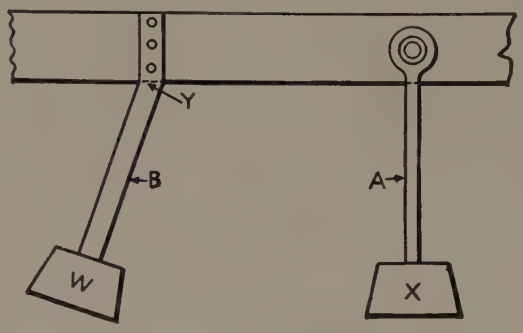


FIG. 70. ILLUSTRATING WRENCHING STRESS IN NIPPLES

are in tension. But the most severe stresses are those due to tubes overheating as shown in Sects. 249 to 255. Assume that such tube is overheated only 100 deg. and that too only in the portion over the fire, which assume to be 40% of the tube length. The resulting expansion of a 4-inch No. 10 gauge tube will produce on the header a thrust of 13,666 lbs. unless the header yields! If the tube heats enough to burn, the thrust will be many times greater, and even then the action will not be the same in *all the tubes,* so some will buckle as shown in Fig. 45, while others will stretch, and that such stretch is permanent is proved by the fact that when bottom tubes have to be renewed, *a new tube of the original length often proves too short.* Clearly, in every case where the tubes below expand more than the drum above, or the lower tubes thrust the bottom of the header outward, the nipple between header and drum is subjected to a cantilever action which increases its tendency to leak or to fail.

244. That the magnitude of the thrust on a straight tube due to expansion is often much greater than above computed is shown in *Strength of Tubes a Factor in Boiler Design,* in *The Boiler Maker,* November 1921. In his final paragraph this writer points out another evil seldom suspected, as follows:—"It follows then that the greatest probable stress will be that due to the tubes being too rigidly held to permit sufficient expansion. As is well known, *steel under a high stress will corrode much more rapidly than when lightly stressed,* so it is of the highest importance to ensure that the tube sheets will breathe sufficiently to allow the tubes to expand."

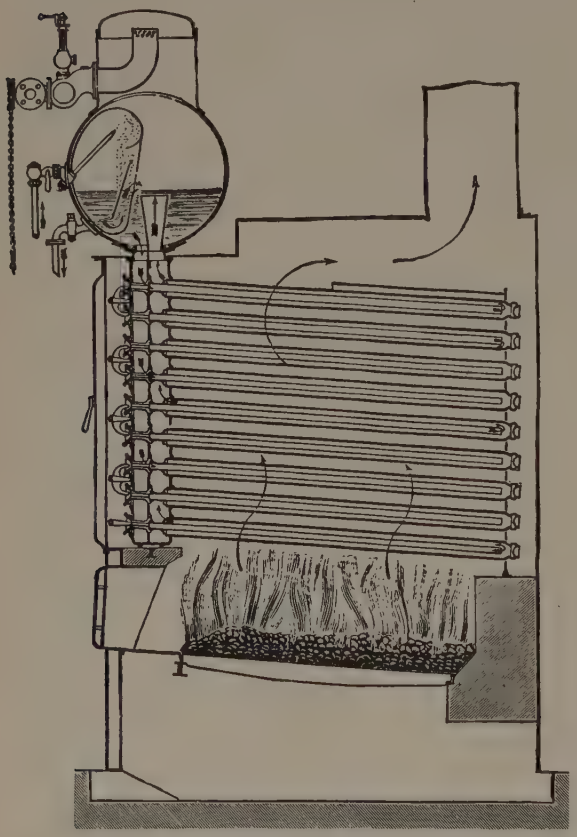


FIG. 71. NICLAUSSE BOILER

245. It was this admitted impossibility of obviating the severe expansion stresses resulting from placing straight tubes between parallel flat surfaces which lead to boilers with headers at only one end of the tubes so that the other end is free to expand. The Dürr, Thornycroft-Marshall, and Niclausse, all evolved in Europe, are typical examples. They so prove the prevalent lack of understanding of the necessity of fast and free circulation, and the disastrous consequences of permitting *mechanical details alone* to supplant proved technical requirements as to rapid and safe steam generation, that we shall illustrate the latter design. Fig. 71 shows the general scheme from which it is clear that it is lacking in water endurance surface, steam space, and means of heating the feed and depositing solids before the water passes into the tubes over the fire. Fig. 72 shows the water circuit, consisting of a partitioned front header to which are attached outer steam generating tubes and inner water circulating tubes shown in detail in Fig. 73. Here A is the header, B the steam generating tube, containing at its upper and lower parts inside the inner header compartment slots C to permit escape of steam, and D is the circulating tube into which water flows after passing from the drum down the front header compartment.

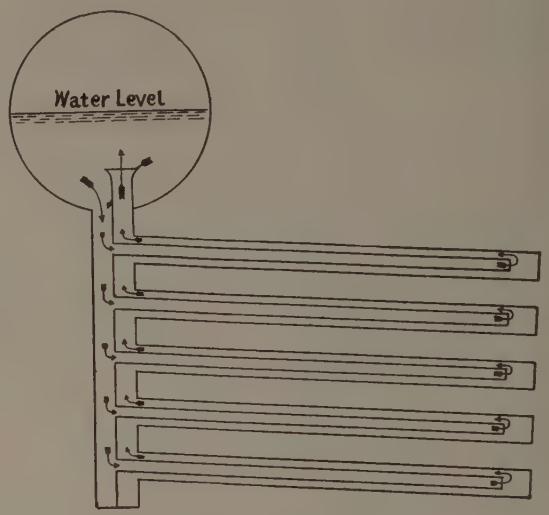


FIG. 72. WATER CIRCUIT OF FIG. 71

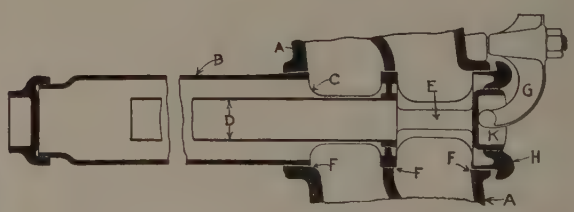


FIG. 73. TUBE AND LANTERN OF FIG. 71

The front ends of tubes B are upset, thickened, and fabricated into the complicated shape terminating in the annulus H into which is screwed the plug K forming an extension of tube D, and this intricate assemblage of parts within the header is called the "lantern." The joints F, F, in the outer header walls are *ground* to a tight fit, while the other joint F in the center wall is not necessarily made so exact. The whole assemblage is held in place by the arch bar G. These illustrations are from Robertson's *Water Tube Boilers*.

A more beautiful illustration of "how not to do it" would be difficult to imagine. When a design like Fig. 32 has been proved deficient as to its water passages, it is clear that the above arrangement is so much more deficient that it was foredoomed to failure. At every stage of its progress the water flow is throttled severely. Apart from the certainty of choking the passage with incrustation unless pure water be used, it is clear that if this design be operated at high ratings the steam generated in the tubes over the fire will be trapped, hence such tubes overheat. This regularly happened. See *Report of the Committee on Naval Boilers* in Bertin and Robertson's *Marine Boilers*, p. 631, in which it is shown that the bottom tubes so distorted that the Report says:—"with the Niclausse, and also with the Dürr boiler, considerable bending of the tubes of the bottom rows *must be expected*, and it will be necessary to straighten these tubes when the amount of bending exceeds ¾ inch." Imagine such a thing in a power plant of today!

In a boiler designed for *results*, not only is it necessary to have free circulation, but unless an economizer be used the steam should all be generated in about the first two-thirds of the boiler heating surface measured from the furnace, so that the remainder efficiently abstracts the heat from the cooler gases and heats the incoming water up to the boiling point. Such is impossible in this design. If the upper tubes generate no steam but merely heat the water, the effluent so heated should then be delivered into the bottom of the tubes which do generate steam. But instead of that it is delivered into the up-comer and mingles with the current of emulsified water and steam, hence unless it has been brought up to the steam temperature it will *condense some of the steam in the up-comer*. To prevent that it is necessary to generate steam in all the tubes. Experiments reported in *Marine Boilers*, above quoted, p. 206, showed that steam *actually was* generated in every tube, hence the breeching temperature must be high. These experiments are plotted in Curve C, Fig. 175, and show the *steam generated* all along the heating surface, while curves A and B represent only heat absorbed. See Sect. 450.

Such designs only accentuate the fact that the whole header scheme is wrong in principle when high operating capacity is wanted, as proved by Sects. 75 and 76, and that the preceding boiler merely carries it to an extreme which makes this self evident.

Naturally this design primes severely, and this is aggravated by the funnel at the top of the up-comer, which increases the spouting action of the effluent, and explains the presence of the objectionable steam dome.

That this design is equally deficient mechanically will appear from its multitude of parts, ground joints, etc., and Hutton's statement in Sect. 547. In consequence, it has disappeared from the market, at least in the United States.

246. Yet this boiler was once in high favor and was extensively used not only in the Navies of Europe, but in the Mercantile Marine and the United States Navy, which corroborates the statements of Mr. Azbe, Prof. Lucke, and M. Bertin quoted in Chapter 1 to evidence the fact that *even today many of the elementary principles underlying correct boiler design are neither realized nor appreciated*, in consequence of which vast sums of money are invested in boilers which yield a return far below what can be produced by designs which are technically correct and available today at a reasonable price.

247. Water Leg Designs unquestionably have less restriction in their circuit than have nipple types, hence their circulation is somewhat better. They also obviate the loss due to air leakage inevitable between headers of the kind shown in Figs. 18 to 30 and 68, and the discussion in Sect. 241. They require staybolted construction which is fiercely assailed by makers of some competing designs.

The Kidwell boiler does not use such construction hence our opinion of it is free from any bias. We therefore suggest that any one who reflects that every locomotive in the world, and the Scotch marine boiler which permitted the development of modern high-power marine engines, use this identical construction it is evident that it has made good and that the attacks on it are

based on neither statistical fact nor sound engineering reasoning.

Therefore, nothing herein contained is to be construed as meaning that *properly designed* staybolt construction is structurally objectionable. Any deficiency herein urged arises from the fact that thus far such designs as use that construction do not provide proper proportions for the water circuit, the consequences of which are herein shown.

248. Figs. 74 and 75 show a horizontal and vertical section through the connection between header and drum in Figs. 66 and 67, from which it is clear that the water passages between the bridge pieces are greater than can be got through nipples. But the boiler in Fig. 32 has even more liberal water passages, yet the analysis of that figure, in which every advantage is given to the design, shows that it cannot meet the absolutely essential requirement that the maximum water speed take place over the fire and in the upcomer, because such result can never be got except by so arranging that the smallest area in the circuit is placed where the greatest water speed must be.

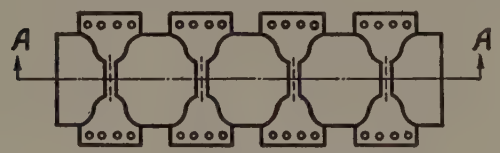
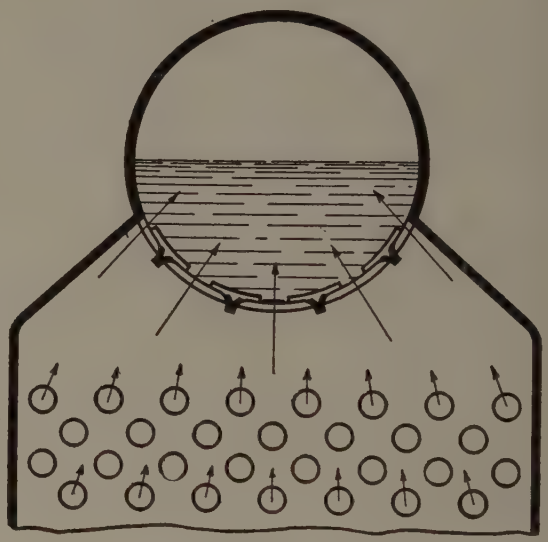


FIG. 74. THROAT TIES OF FIG. 75

249. Valuable information on this point is given in *Circulation in Horizontal Water Tube Boilers,* by Paul A. Bancel in A.S.M.E. Transactions for 1915. The discussions are particularly illuminating. Hosea Webster states, p. 1040:—"The lack of tube troubles in many boilers with the latest types of furnaces, daily operated at from 3 to often over 4 times their normal rating, indicates that *in present day water tube boiler designs, ample provision is made for efficient circulation.*" It is to be regretted that this commentator failed to name some places where with header types of boilers which were under discussion such ratings are developed *for any extended periods* other than short peak loads, and that he did not elucidate how the *present day designs* such as Figs. 35 and 68 have any better circulation than older designs like Fig. 30, since according to all technical principles the former are decidedly the less efficient as to circulation. It would be particularly interesting if he could continue the same line of thought to the extent of explaining why, if the increased degree of throttling in later types of boilers many tubes high makes "ample provision for circulation," the same process does not show such result in the Niclausse boiler in Sect. 245, etc. See footnote to Sect. 471 for an interesting parallel of the kind of reasoning above referred to. Also see Sect. 253, and Mr. Kent's remarks in Sect. 115 as to the comparative speed of water flow in the different parts of header designs. Note also Gebhardt's statement in *Steam Power Plant Engineering,* p. 167, that "It is a question if there are 30 plants throughout the country operating continuously day in and day out at 175% of rating."



SECTION A-A

FIG. 75. WATER PASSAGE INTO DRUMS OF FIGS. 66 AND 67

C. L. Hubbard, *National Engineer,* November, 1921, under caption *Increasing Boiler Capacity,* says:—"While boilers *in first class condition, designed with special reference to heavy overloading, may be forced to 200 or 300% of their nominal rating, it is not, in general, advisable to exceed about 150% in the case of boilers not built especially for this condition of operation.* For example:—Certain types *prime* excessively when forced beyond this point, while the effect in others is to produce an *unstable*

water line. Another well known type, with standard construction, *fails to circulate properly* when forced beyond 250% of the nominal rating, and it is not well with this boiler to exceed 200% on this account."

But Mr. Bancel's reply to his critics is terse and to the point. "He does not believe that 'the circulation of boilers is good enough,' first; because cases of tube failures, some of which caused loss of life, have occurred *where the tubes were new and it was known that they were free from scale;* second, because boiler loads and furnace temperatures are constantly increasing; and third, because the investigations undertaken indicate that present designs do not conform in several respects to the necessary requirements for the maximum delivery of water through the tubes nearest the fire.*" (See Figs. 80 to 85, and Sects. 145 and 265.) And again, Mr. Bancel says:—"Mr. Webster intimates that attempts to improve upon the circulation in water tube boilers are unnecessary because of the perfection of present day design. A recent article in *The Locomotive,* published by the Hartford Steam Boiler Inspection and Insurance Co., lists 20 cases of tube ruptures in water tube boilers." Further illuminating information as to this is contained in *Boiler Explosions, July 1, 1915, to July 31, 1916,* in *Power,* Nov. 7, 1916. In this, note the large number of headers which failed.

250. The causes of such ruptures are not all given above. The citation from *Marine Steam* in Sect. 235 shows another reason inherent in all designs whose water circuit produces a slow velocity in the tubes. On this point Dr. D. S. Jacobus in *The Generation of Power,* in *Journal of the Franklin Institute,* Dec., 1910, says:—"A loose scale may also cause trouble. The action of such foreign substance inside the tubes is to cause blisters, which ordinarily will bulge out and possibly open slightly. If it so happens that there is a flaw in the tube at the point where the blister is formed, the tube may open up, and if the opening is large enough an accident may result if anyone is caught in the confined space and cannot get away from the boiler." Every plant operator will note the evasiveness in this whole statement. Anyone who has seen *tubes blow wide open* knows that if no flaw is accommodating enough to be present where the scale drops, the pressure will soon create one when the tube overheats, and there is no surety against it tearing wide open. It is also something of a novelty to assert than an accident is dependent upon anyone being caught in a confined space, or even being near by. Our observation has been that tubes which fail by overheating do so without respect to the propinquity of persons. "On water tube boilers, *particularly the horizontal types,* it will often be found that the first row of tubes develop a *number of small bags.* As many as 10 have been counted on one tube." —*Power,* Sept. 27, 1921, p. 492. Each of these will surely rupture if such tube is continued in use.

251. Whence Comes the Loose Scale Responsible for These Tube Failures? The answer will be clear from reading Sects. 120 to 122. If the boiler be shut down *even once,* and the tubes containing a deposit consisting of both precipitate and scale become cold and contract, such deposit will crack off in places, and when the boiler starts up again the water will, where its velocity is considerable, sweep such fragments of scale along in the stream until the tubes are reached, then will *drop it because the water speed in the tube slows up* exactly contrary to Sect. 49. See Hutton's statement, Sect. 122. In consequence, even to shut down a header type of boiler for a night involves a risk unless the tubes are cleaned out before firing up again. This is recognized by some operators. "Mr. Lewis thinks I am pessimistic regarding tube failures, especially those due to floating scale. *It isn't pessimism to face facts.* I have seen a great many tubes fail in *horizontal water tube boilers* after the boilers have been let down and then fired up again without turbining the bottom rows. I want to emphasize again the necessity of turbining the two bottom rows of tubes *every time* the boiler is shut down. Turbine *all* the tubes if possible, but be *sure to clean the two bottom rows.*"—Waldo Weaver, in *Boiler Tube Failures* in *Power,* Nov. 25, 1919. Com-

*"In closing I might mention an incident with regard to circulation which has caused me considerable thought. If the tubes exposed to the fire in all of the modern horizontal straight tube type boilers are provided with a sufficient circulation; i. e., a sufficient water supply and steam delivery area, why is this type of boilers, in Marine service, provided with auxiliary feed water lines discharging directly into the lower row of tubes for operation when running at high ratings?"—W. N. Flanagan in discussion of paper cited in Sect. 155.

pare with Otley's statement, Sect. 150. If this means anything it means that every time a header type of boiler is shut down over night it must be opened up and cleaned next morning if the element of risk of rupturing tubes is eliminated. For confirmatory evidence, see p. 52 of *Tests of Stirling and B. & W. Boilers,* wherein a new and clean header type of boiler in charge of the builder's engineer ruptured two tubes from this cause. "The scale from the whole length of one of the cracked tubes was carefully scraped out, and would just about fill an ordinary small-size match box."

252. Since, as above stated and further shown in Sects. 119 to 122, header types gather incrustation on the tubes over the fire faster than done by certain other designs, it is interesting to note that Dr. D. S. Jacobus, in *Boiler and Furnace Economy,* in *Mechanical Engineering,* December 1921, says when discussing high boiler ratings:—"High capacities of the sort should of course *not be attempted without the very best of feed water* and the highest class of attendance." He also insists on the necessity of clean feed water in the first quotation in Sect. 25(b). It certainly follows that extreme caution should be used as to attempting high ratings with *any boiler so designed as to sweep the precipitates into the tubes over the fire,* rather than to cause them to drop into a mud drum.

Unless the steam is swept from the generating surface as fast as formed, the danger of a tube failure due to decomposition of magnesium chloride, or to oxidation, is greatly increased, as shown in Sects. 149 and 150.

253. It would be difficult to conceive of any more conclusive or rigid proof of the inadequacy of header types as to rapidity of circulation and safety against the overheating and rupturing of tubes. *If this was true in the past, it is far more true now, because in order to crowd more power into the same space, the number of tubes in height is steadily increasing—24 to 27 being used at present—and the deficiency in circulation and liability of tubes overheating and bursting increases as the number of tubes high in a header is increased.* This is due not only to the increased frictional resistance of the water circuit, but also to the greater tendency of the steam bubbles to slip through the water instead of carrying the water along with them, as shown by Bancel in the concluding paragraphs of Sect. 51. A glance at Figs. 76 and 77 reveals throttling of the circulation to a degree not to be tolerated by any one who seeks high capacity with durability.

254. Breckenridge, pp. 163 and 164 of Bulletin 325, U. S. Geological Survey, *A Study of 400 Steaming Tests,* gives results of experiments determining the speed of water in a water leg boiler and says:—"The important point is that the circulation *rapidly drops behind* the amount of steam made (per cent of rated capacity developed), especially at high rates of working. * * * This failure of circulation to keep up proportionally with demands on it must *decrease the efficiency of the boiler at higher rates of working,* by allowing a proportionally larger percentage of the water heating surface to be covered with

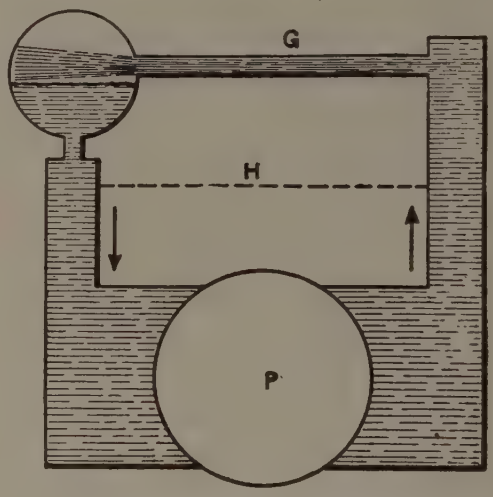


FIG. 76. HORIZONTAL SPOUTING DUE TO RESTRICTED WATER PASSAGES

steam bubbles, thus virtually reducing the heating surface," and of course increasing the danger of overheating and rupturing tubes. "In an earlier experiment the circulation indicator was placed in the third row of tubes from the top of the boiler, and it was found that the rate of revolution was very slow indeed."—*Ibid.* Similar experiments on the "Standard Boiler" of the Emergency Fleet Corporation not only showed the same thing, but at times the indicator did not turn at all and at *other times it reversed,* proving the existence of back boiling! See Sect. 59. It was found that the tubes connected to the middle third of the headers had *no circulation at all!* Under such conditions these tubes are not only useless as heat absorbers, but they will fill with mud (see Sect. 119), and pit because of stagnation of the water in them.

255. Again, some arrangements of baffles may cause slowing up of the water speed in tubes much nearer the fire. Thus:—"The second row of tubes (from the bottom of a header design) had considerable scale, as well as an accumulation of mud. One was almost choked and several were about half-choked with scale and mud. In the third row the tubes were not nearly so bad as the second."—*Tube Trouble from Dirty Feed Water,* in *Power,* November 22, 1921.

256. Hence Hosea Webster's statement that "ample provision is made for efficient circulation" is not substantiated by any evidence at hand as to header types of boilers. Since the velocity of water flow in Kidwell boilers is manyfold greater than the maximum possible in any header types, and its water circuit is correctly designed while in header types it is not (Sects. 475 and 481), if Mr. Webster can produce conclusive evidence that the latter types can safely be "daily operated at from 3 to often over 4 times their nominal rating" he will then automatically confirm that the Kidwell boiler can operate at manyfold times such ratings, since the maximum possible safe ratings are directly proportional to the speed of water flow. The superiority of the Kidwell boiler in this respect is already fully proved in the sections just referred to, and by what it is actually performing in daily operation.

257. Schemes for Reducing the Evil Effects of Deficient Circulation. Final evidence as to the inadequacy of header types is afforded by the numerous schemes advanced to overcome, reduce, or modify the deficiencies above set forth. We will present only a few out of a vast number, and these are all due to men actively engaged in operating or exploiting boilers, and such men do not waste time devising things for which there is no demand.

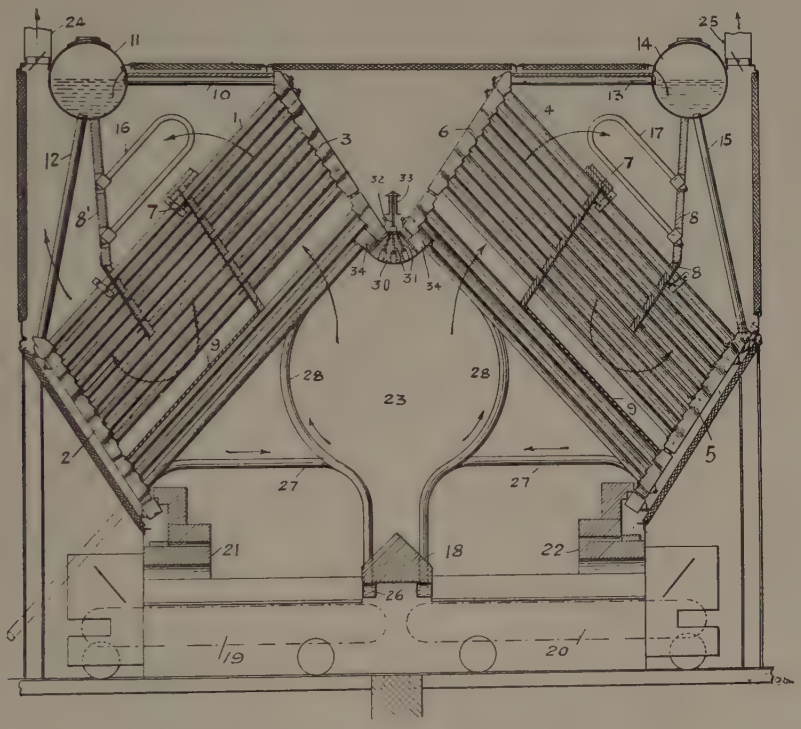


FIG. 77. A DESIGN BY D. S. JACOBUS

258. One class of such devices attempts to reduce the trouble by increasing the area of the nipples connecting the headers to the drums above. Thus, while in Figs. 30, 35, 45, etc., 4-inch nipples are used, one prominent Canadian manufacturer uses 4½-inch nipples and claims that it makes a great improvement, though it is apparent that the percentage of increased area is too small to make much difference. Another scheme for increasing the nipple areas is shown

in Fig. 78A. This doubles the area as usually provided and is undoubtedly an improvement in that respect, but is impracticable except with this cross drum arrangement which reduces the water endurance surface and steam volume to

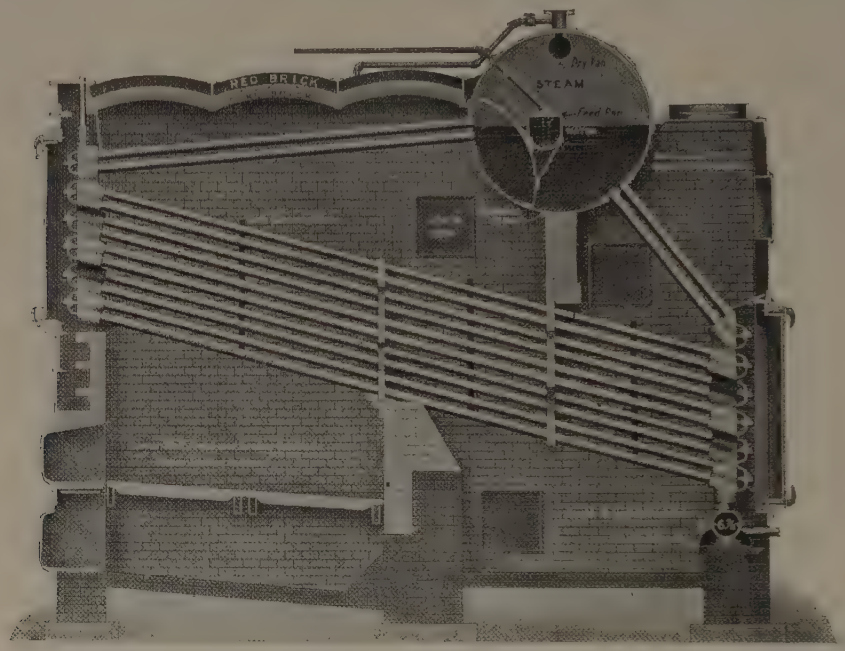


FIG. 78A. HEADER DESIGN WITH TWIN NIPPLES

an extent which apparently offsets its advantage. The complications in the drum are likewise open to some objection.

259. In water leg designs attempts are made to promote circulation by increasing the cross section of the up-comer headers. This looks reasonable at first glance, but it fails because of the facts set forth in Sect. 51. Thus, if in Fig. 78B the width of header on line AB is greatly increased, the water flowing from the tubes *decreases its velocity* the moment it enters the header, hence the emulsification of the steam is reduced, and the bubbles aggregate to large size, then slip up through the water, so that instead of causing an upward water flow they frequently cause a down flow next to the header walls as indicated by the arrows, and this decreases the circulation. This is well illustrated by the drinking water receptacle in Fig. 79. Notice how the entering air forms bubbles which because of the reduction of pressure increase in size as they rise, (Sect. 57[d]) and that the larger the bubbles the greater their slip through the water, per Sect. 51. Finally note that *only the water contiguous to the bubbles is pulled upward by them*, while toward the sides of the bottle there is a down-flow of water which duplicates the action in the enlarged header as above described. See last quotation from Bancel in Sect. 51, also footnote to Sect. 121.

260. Another class of such devices partitions the header so as to compel the downflowing water to reach the bottom tubes first and thus prevent them from going dry as mentioned in Sect. 145.

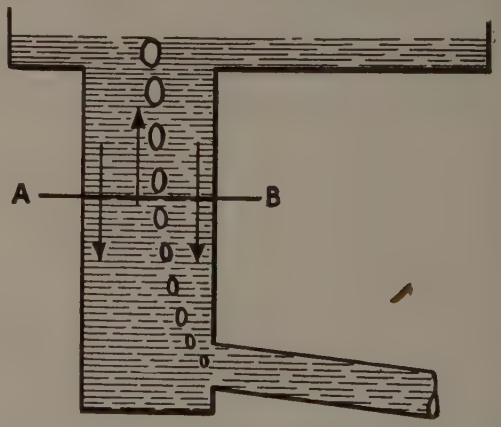


FIG. 78B. SHOWING EFFECT OF WIDENING HEADERS

Fig. 80 from *Die Dampfkessel*, by Spalckhalver and Schneiders, published in Berlin, shows one such device. It obviously increased the resistance to water flow and its complication makes it impracticable.

261. H. Rosenthal of London devised the scheme shown in Fig. 81A. He provides the tubes over the fire with a separate up-comer, *thus admitting that the usual up-comer area is insufficient.* This arrangement improves the circulation, but as it interferes with access to the tube caps of the inner headers it is impracticable. In other respects this design has the same limitations and deficiencies as Fig. 68, for which see Sects. 234 to 236.

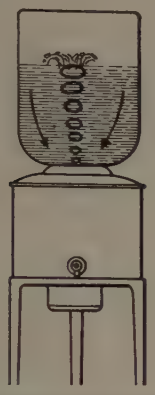


FIG. 79. SHOWING SPRAY FROM EXPLODING BUBBLES

Another English designer attempts to utilize this scheme by arranging the parts as in Fig. 81B. Apart from the general complication and difficulty of renewing the tubes connecting the bottom headers to the drums, these cause the gas space between the upper tubes to be too wide.

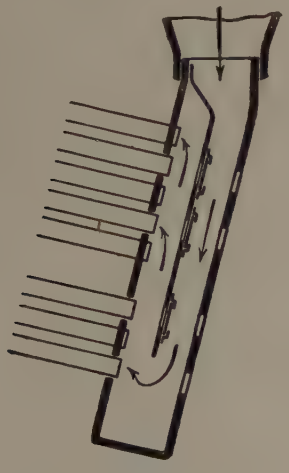


FIG. 80. A GERMAN DEVICE

It is evident that the identical water levels shown in drums A and B are impossible when the boiler is steaming, and that drum B will fill with water to level of the top tube, hence the

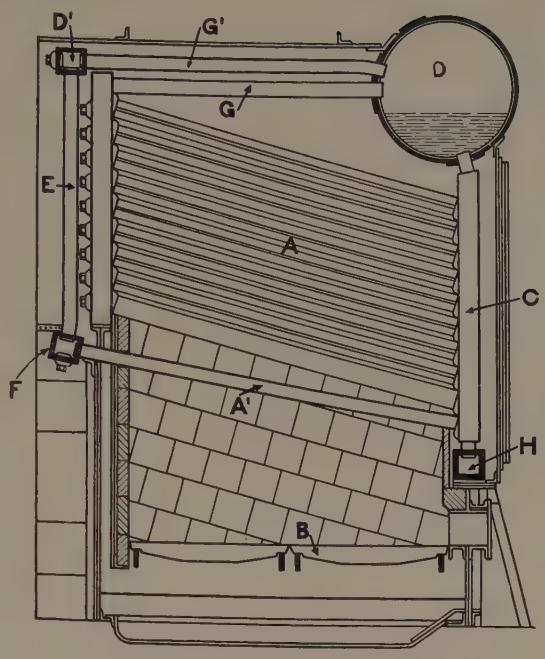


FIG. 81A. ROSENTHAL'S DESIGN

water in the gauge glass will fluctuate regardless of which drum the glass is connected to, and the boiler will also prime.

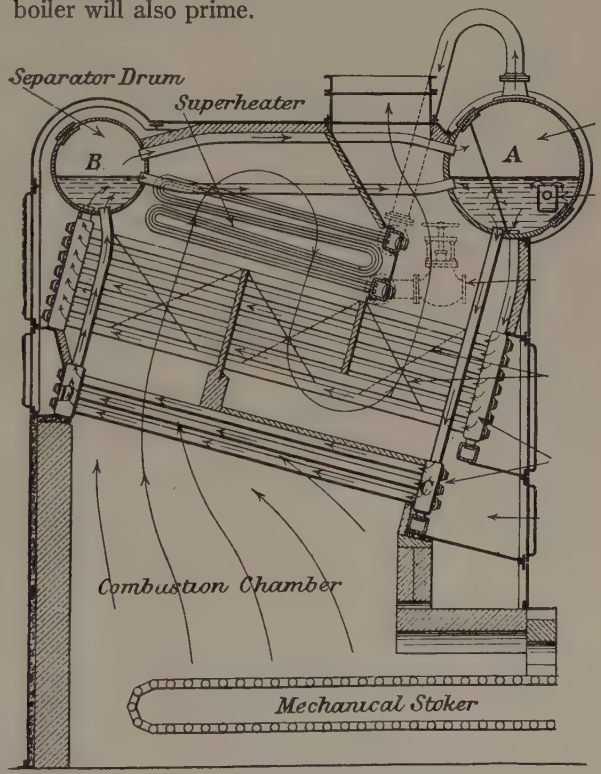


FIG. 81B. AN ENGLISH DESIGN

262. H. E. Boyrie worked out the method shown in Fig. 82A. The funnel 21 and pipe 19 provide a separate up-comer for the two lower tubes and deliver their effluent above the water line in the drum. This causes spouting and wet steam. The other tubes are supposed to get along the best they can with the attenuated water

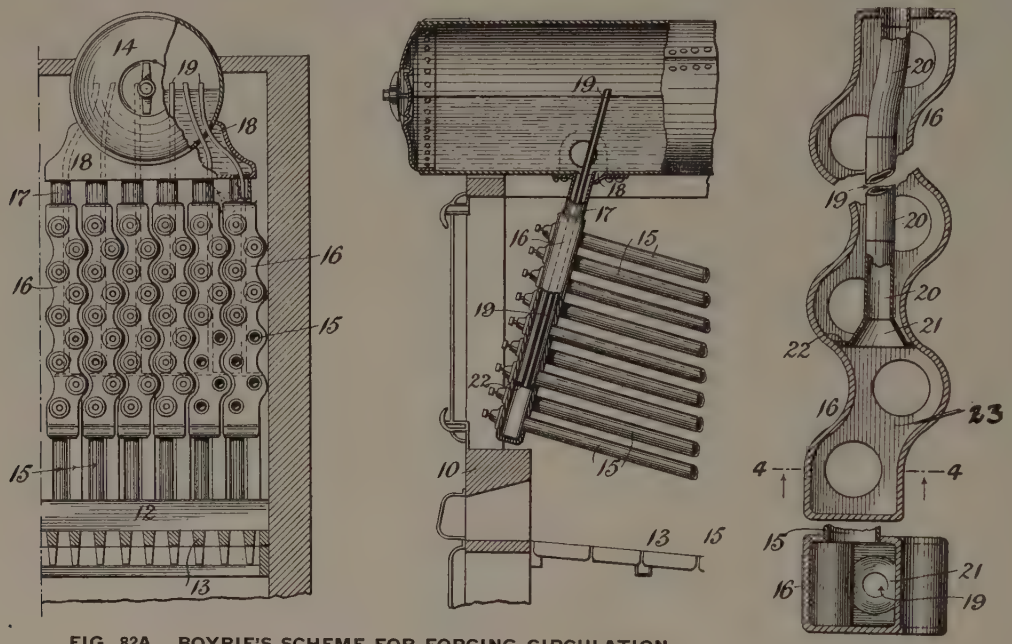


FIG. 82A. BOYRIE'S SCHEME FOR FORCING CIRCULATION THROUGH THE LOWER TUBES

area left between header walls and the tube 19, which is clearly so small that the water speed through these tubes would be extremely slow, hence inefficient as to absorbing heat, and certain to fill the tubes with sediment, and also cause pitting.

Boyrie also produced the scheme shown in Fig. 82B. Like Solignac in Sect. 272 he plugs the tubes, but at the outlet instead of the inlet, and then inserts through the plugs the small bore tubes as shown. The purpose of these is to draw off steam as fast as formed, while leaving the water behind.

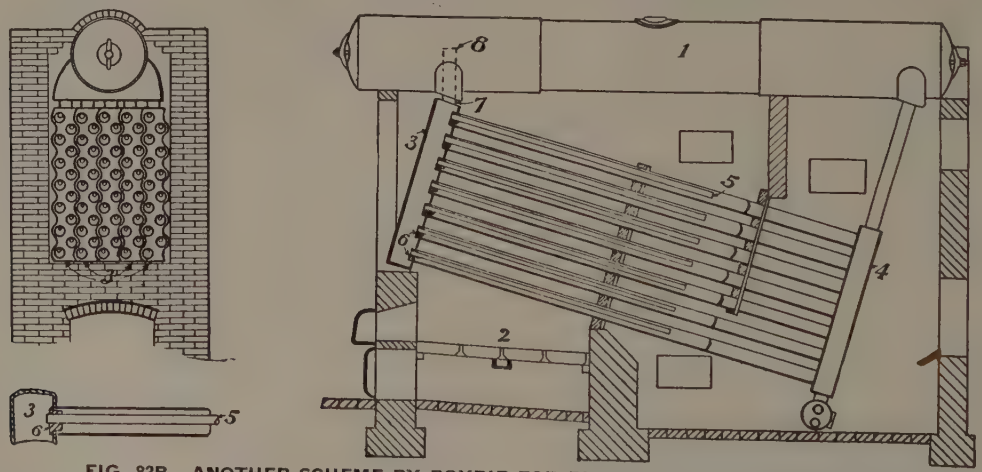


FIG. 82B. ANOTHER SCHEME BY BOYRIE FOR PRODUCING THE SAME EFFECT

A glance will reveal that the space between outer and inner tube toward the upper header would fill with steam and drive out the water, just as in a pneumatic trough. Hence the larger tubes would quickly burn. As this feature alone is fatal further discussion is superfluous.

263. C. L. Anderson proposes to plug the upper tubes except for a small opening at the top of the plug, which is left so the steam generated in these tubes can pass out, while the water is practically stagnant, as shown in Fig. 83. This is done to compel a rapid flow through the lower tubes and thus protect them from burning. This scheme reduces the efficiency because it prevents circulation in the upper tubes, and also will greatly increase the liability of such tubes to fill with mud and to pit.

264. Another contrivance for compelling a faster circulation in the bottom tubes, when the gas flow is parallel to these tubes, is to place a row of tiles over the first, second or third row of tubes from the bottom, and thus compel the lower tubes to absorb more than their share of the heat, hence generate a greater quantity of steam which in its effort to escape automatically increases the water flow through those tubes. This, however, reduces the efficiency of the upper tubes since it decreases the water speed through them which in turn increases the liability of sediment to accumulate in them. Further, if the boiler is worked at sufficiently high ratings to accumulate steam in the top of the lower tubes, as shown in Fig. 1, the white hot tiles in contact with the steam locked tube may cause the tubes to overheat and burn. For a striking proof of

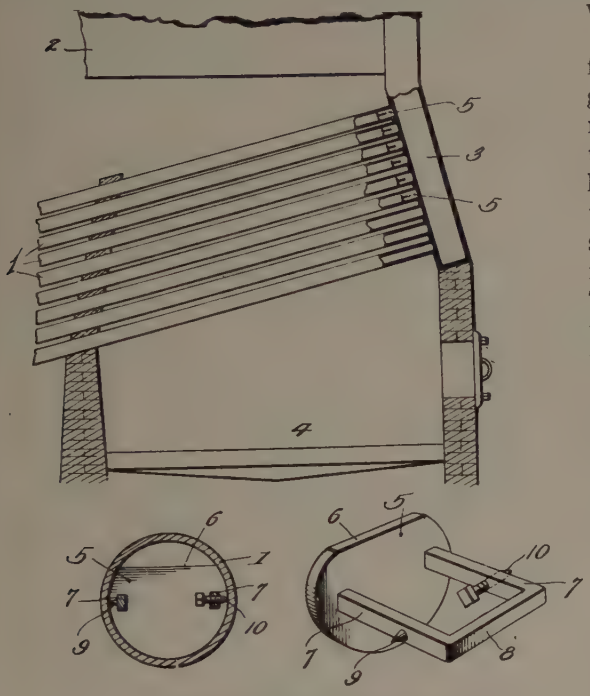


FIG. 83. ANDERSON'S DEVICE FOR COMPELLING CIRCULATION IN BOTTOM TUBES

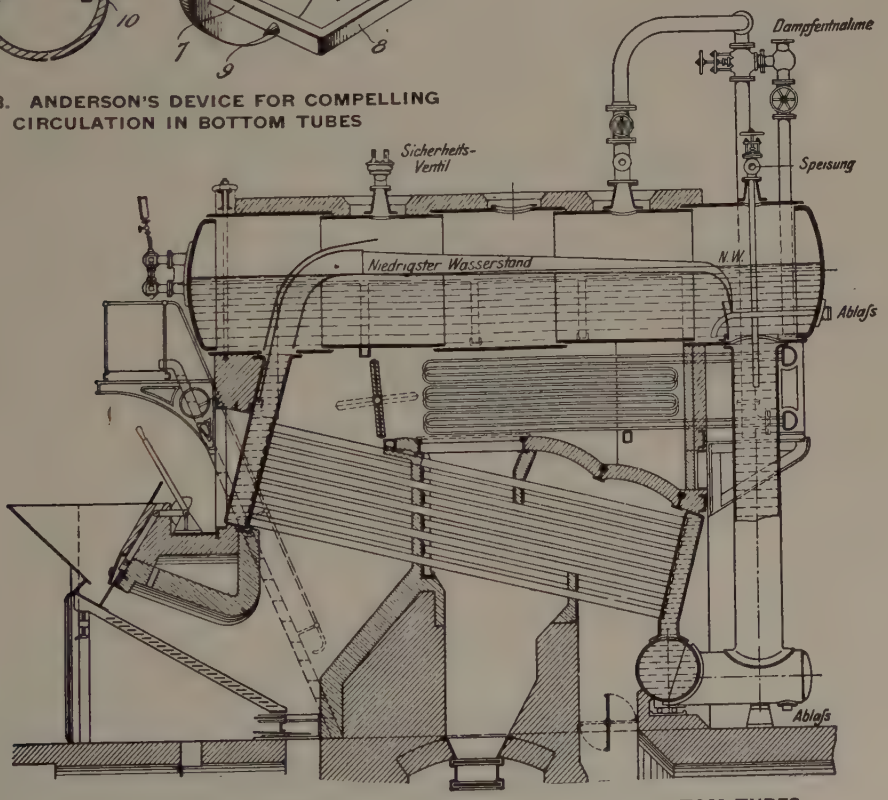


FIG. 84. A SCHEME FOR GETTING WATER TO THE BOTTOM TUBES

UNITED STATES PATENT OFFICE.

WILFRED D. CHESTER, OF SEWICKLEY, PENNSYLVANIA, ASSIGNOR TO THE BABCOCK & WILCOX COMPANY, OF BAYONNE, NEW JERSEY, A CORPORATION OF NEW JERSEY.

WATER-TUBE BOILER.

1,124,392. Specification of Letters Patent. Patented Jan. 12, 1915.

Application filed May 31, 1911. Serial No. 630,476.

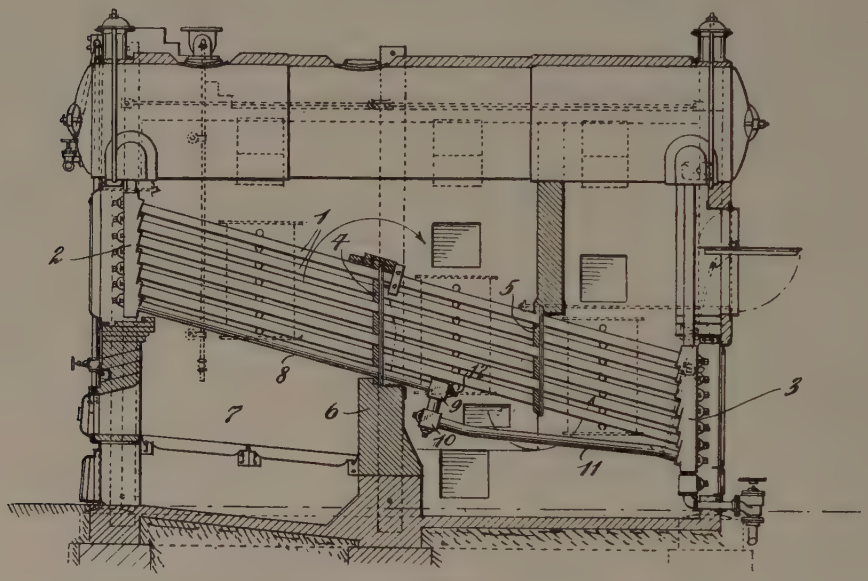


FIG. 85

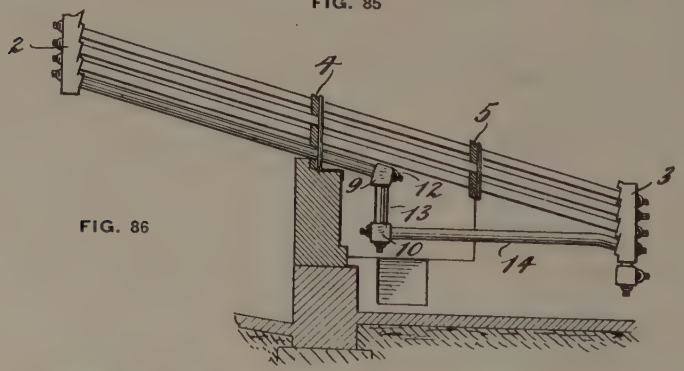


FIG. 86

CHESTER'S SCHEME FOR REDUCING THE HIGH COST OF TUBE RENEWALS IN HEADER AND NIPPLE BOILERS

this see result of changes in location of baffle tiles at Detroit Edison plant in third paragraph of *The Constitution and Properties of Boiler Tubes* in *Power,* Dec. 14, 1920. Also see Sects. 254 and 255.

265. Fig. 84 shows another method which has been tried in various countries. This is old, but it is seldom used in the United States although modifications of it have been worked out in various patent applications. See U. S. Patent No. 1,141,520 to J. E. Bell, Water Tube Boiler, June 1, 1915, and Figs. 8 and 9, in *Steam,* 35th Edition, p. 41. One Canadian manufacturer has used it to some extent, but it has been more widely used in Europe, and Fig. 84 is from a German design. Also note Fig. 131.

The frequency with which this has been tried is one more clear-cut proof of inadequate circu-

lation in header boilers, and the failure of the method to come into general use proves that it, like the many others tried out, is unequal to the task of redeeming a design which was technically incorrect at the start.

266. W. Chester meets the problem in a different and more heroic way, as shown in Figs. 85 and 86. He frankly admits that the lower tubes fail frequently, so undertakes as an economist to reduce the expense of renewing tubes. He makes the bottom tube in two lengths united by joint boxes and a nipple, so that renewal is necessary for only the length of burned tube over the fire. This scheme greatly increases the resistance of water flow in the bottom tube just where such resistance does the must harm, and how an operator is expected to enter into the restricted space available, and do the repairing, is not explained in his patent.

267. Prevention of Spouting and Distorted Water Line. Figs. 9 to 12, 64, 103 to 105, etc., and the explanations thereof show the causes of unequal levels, and Figs. 65, 68, 77, etc., some devices for reducing this trouble. We find, however, that few plant operators realize either the cause, extent, or the numerous schemes tried for overcoming these evils, hence the following will make this more clear.

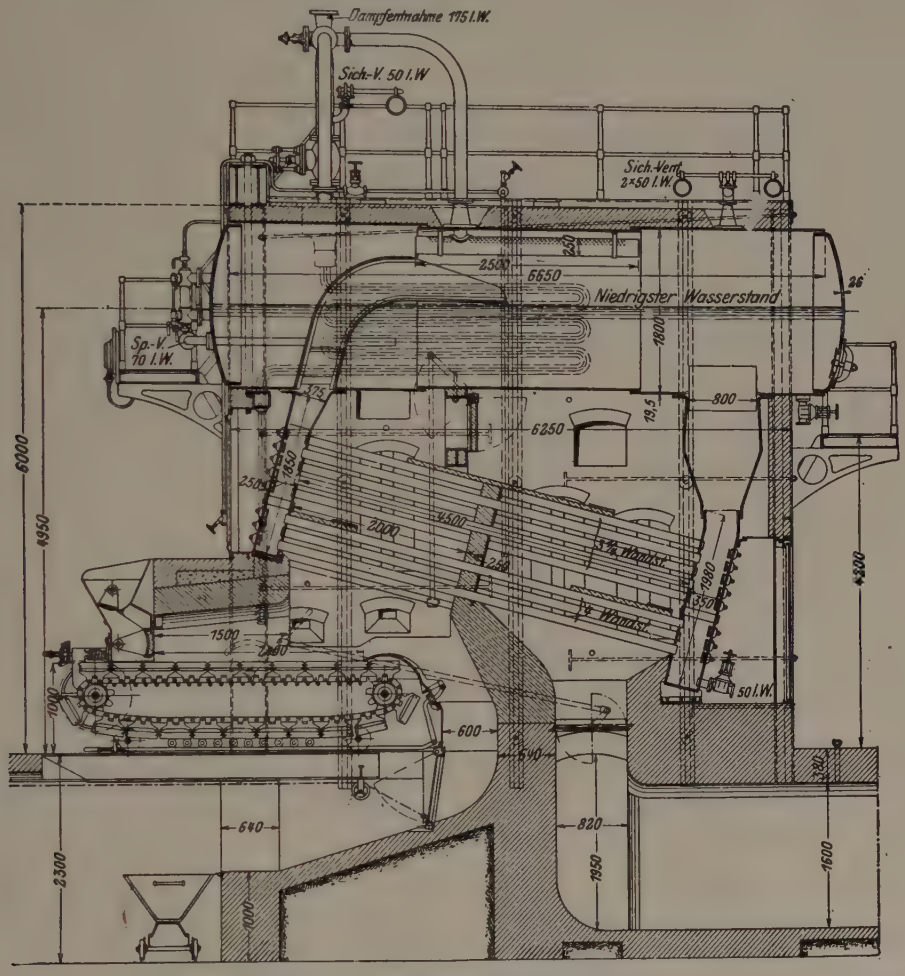


FIG. 87. A GERMAN DEVICE FOR PREVENTING VERTICAL SPOUTING FROM HEADERS AND DISTRIBUTION OF WATER LEVEL

268. Fig. 87 is from *Die Dampfkessel,* by Spalckhalver and Schneiders, Berlin, and it will be noted that the up-comer terminates in a right-angled bend so arranged as to project the effluent parallel to the water surface and thus prevent vertical spouting. It is doubtful whether this

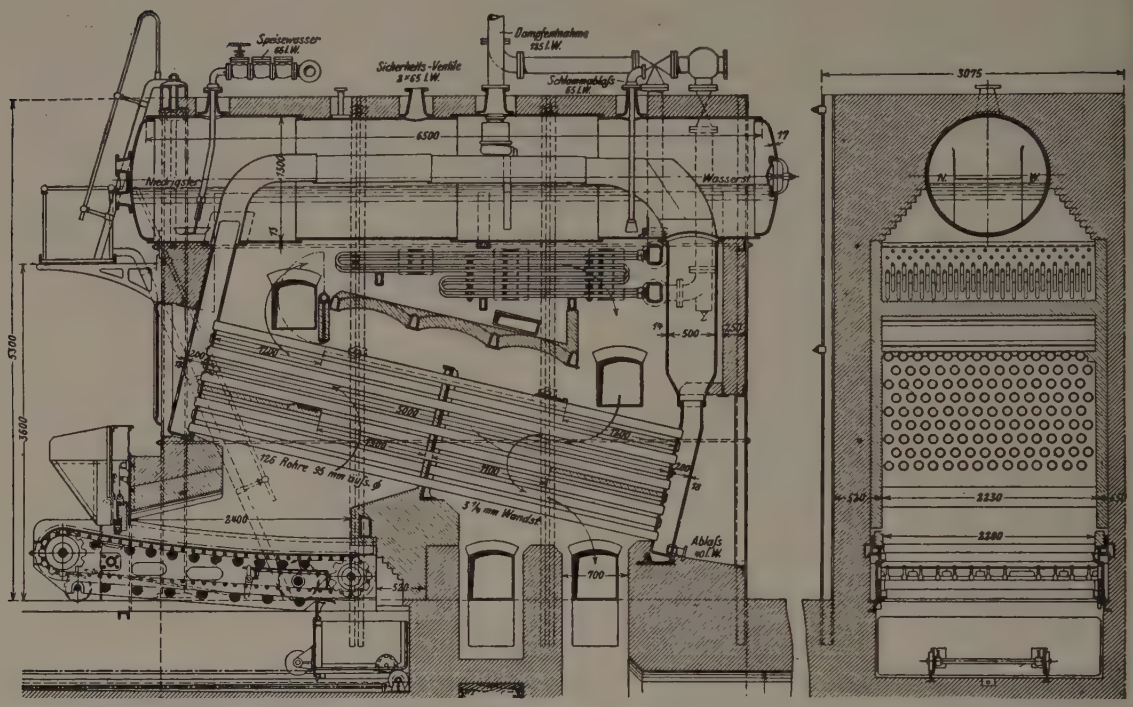


FIG. 88. ANOTHER GERMAN DESIGN TO ELIMINATE SPOUTING AND DISTORTED WATER LINE

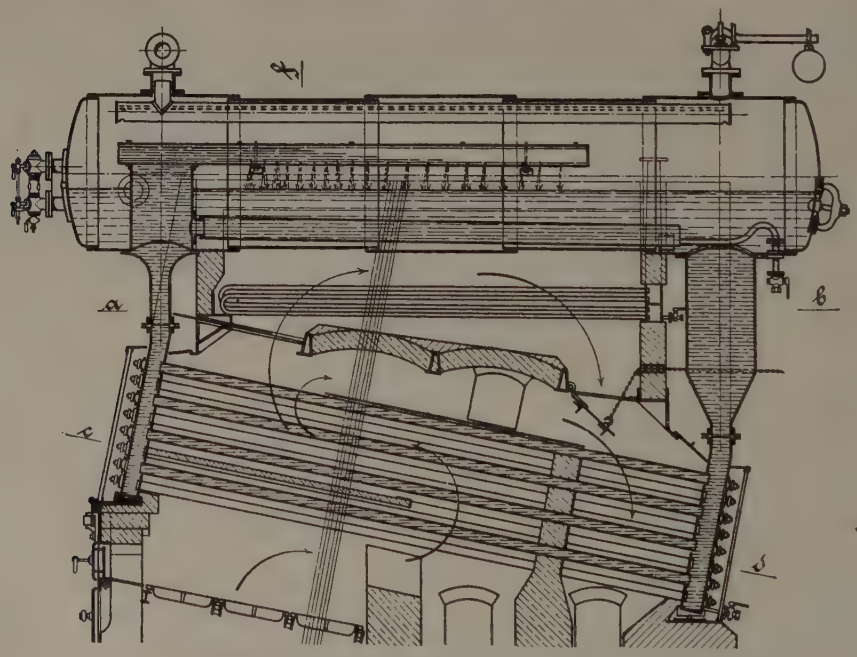


FIG. 89. A FURTHER GERMAN DESIGN TO REDUCE SPOUTING, ETC.

arrangement will to any degree reduce the percentage of moisture carried out by the steam. As arranged, however, it discharges above the main water level, hence diminishes surging of the water in the gauge glass.

269. Fig. 88, from the same source, shows an extension of the idea, and a trough connects the up-comer and down-comer, and apparently all the steam is disengaged from the water while it flows along this trough. Perforations permit

water to flow out into the drum, and this arrangement also prevents sudden surging of the water in the glass.

270. Fig. 89 from *Die Dampfkessel,* by F. Tetzner, Berlin, shows another scheme by which the up-comer outlet is extended some distance above the water line, and terminates in a wide flat trough *closed at the top* so as to prevent vertical spouting, and of such length that all of the water from the up-comer can flow through slits in the bottom of the trough, thence into the main water body below, while the steam continues on to the end of the pipe. This also will prevent violent surging of the water in the gauge class as the load changes.

No such devices have come into use in the United States nor is it likely that they ever will, since American engineers object to such a mass of complication, and the time necessary to detach and remove such parts during cleaning and inspection. Fig. 78A shows the nearest approach to such complication which we have seen here, and it will be interesting to note whether or not engineers will sanction it.

271. A potent objection to all of the schemes above described is that they prevent the water in the upper drum from becoming an active part of the main flow circuit, hence this water becomes stagnant, which in turn causes pitting and corrosion which may quickly become serious. See Sects. 206, 207 and 567. We have seen cases where in some boilers such pitting and corrosion has with certain waters become dangerous even in the small portion of the drums near the ends where the water is relatively stagnant, hence with the devices above described this trouble would be intensified manyfold. This deficiency alone is sufficient to condemn them, but the fact that they have been so thoroughly tried out in Europe proves that Continental engineers have long realized the serious troubles due to distorted water line and diligently sought a remedy. They failed, however, nor was there any solution of this problem until the Kidwell Two-Flow Ring-Circuit boiler appeared.

272. Solignac's Boiler. While Anderson, Sect. 263, throttles the *outlet* of the tubes, Solignac produced in France the design in Fig. 90 which throttles the *inlet* "for the purpose of *retarding the downward current of water from the drum,* and of so limiting its admission to each tube that very little more water may be present than the tube can evaporate."—Hutton, p. 350. The feed is sprayed into the top of the steam space, hence is heated almost entirely by condensing steam, which is not economical and is certain to cause very wet steam.

Like most French designs this one is extremely complicated in detail, and some examples of it provide *a water regulating valve in every tube!* Evidently, unless fed with distilled water the restricted tube openings will quickly plug with scale, and any shortage of water supply resulting therefrom or due to operating at high ratings, will cause the tubes to burn quickly.

As the object of the design is to prevent violent spouting of water and steam from the generating tubes into the drum, it appears that spraying the feed into the steam space nullifies

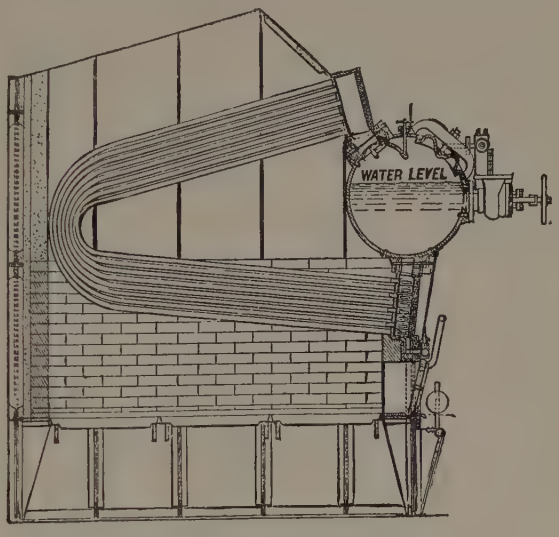


FIG. 90. SOLIGNAC'S BOILER

the effect for which all this complication has been provided, hence the design is not consistent. See Sect. 361 for a case where a similar throttling scheme was used in steam over-comer tubes with equally bad results.

273. Soot Locks in Gas Passages. Sect. 368 mentioned a scheme of baffling which contains such objectionable feature. This defect is frequently found in header types also. Fig. 91 shows a case. "This form of baffling gives trouble due to the difficulty in removing the soot which collects in the corner (marked A in the cut) where the first baffle joins the tile roof of the furnace."—*A Study of Boiler Losses,* Bulletin 78, University of Illinois Experiment Station, page 53.

274. Fuel Efficiency of Header Types. Manufacturers of such types often make voci-

ferous claims that in fuel efficiency they are superior to all others. Even if such claims could be substantiated to some small degree that fact would be far more than offset by more important factors involved in the efficiency of Capital, as shown in Sects. 25(i), 106 to 112, Hutton's statement in Sect. 547, and many other places herein. But the evidence does not support such claims. Their deficient circulation has been proved and that is opposed to high fuel economy and still more so to Efficiency of Capital. Further, in boilers with cross baffles like Figs. 35 and 45 the gas flow does not conform to the principles laid down in Sect. 132. Finally, Figs. 4 and 5 summarize what has been confirmed by many tests. Yet even they do not include the vital consideration pointed out in Sects. 109 to 112, and Fig. 46. If these be taken into account the showing would be even less favorable to header types of boilers.

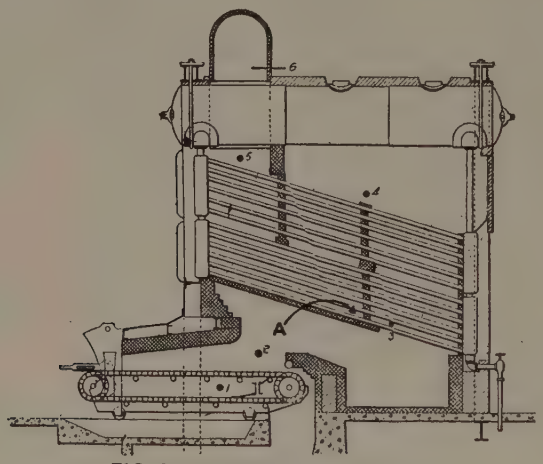


FIG. 91. SHOWING SOOT LOCK

275. Conclusion as to Header Types. It follows that header types *cause the minimum water speed to occur where it should be a maximum, and vice versa, hence are wrong in principle* (See Sect. 52) and cannot by any means whatsoever be modified to operate safely at ratings entirely feasible in boilers with free and accelerated circulation. Their proportion of tube losses as compared with boilers of later and better design is excessive, as shown in Sect. 147. The time and expense of removing, replacing and tightening the multitudinous caps when cleaning is done, is also excessive as compared with better designs now available. See Sects. 140 to 146. And finally, their efficiency as to Capital is less than for other designs available. Evidence to prove these facts is cumulative and conclusive, hence justifies the final judgment of thinking engineers that for boilers carrying other than excessively high pressures, and for stationary plants at least, where high ratings are necessary and reasonable head room is available, *all header types are now obsolete if technical principles, in connection with sound engineering and financing, prevail.* Analogy:—Successful steamboat propulsion began with paddle wheels; *they did good work under the conditions then existing.* But when large and speedy ocean traffic was necessary it was found that even at the limit of development of paddle wheels they were unequal to the requirements of heavy and fast ocean vessels, hence the propeller was invented, developed, and finally used exclusively, for this class of service. The paddle wheel still remains and is useful in a limited field confined to light river and coast vessels. Similarly, for low head room and light rates of driving there will always be a field of usefulness for header boilers, but for the bulk of the world's heavy work this type has passed its zenith and is steadily on the decline.

276. Here enters a point seldom realized. Dr. C. F. Hirschfield in *Power Plant Evolution* printed in *Mechanical Engineering,* Sept., 1921, says:—"At the present time we seem to have reached very close to the limit of ultimate development along the lines which have been followed during the past two decades." This indicates why in order to obtain such results as are produced by the Kidwell Two-Flow Ring-Circuit boiler it was necessary *to go beyond what has been done before,* and to introduce into boiler engineering an entirely new principle, as shown in Sects. 396 and 504.

For the same reason it is clear that to make header types capable of meeting, better than in the past, the requirements of the steadily narrowing field open to them, it will be necessary to abandon the current belief that they are no longer capable of improvement, and to devise means of overcoming some of their more serious deficiencies. See Azbe's remarks in Sects. 6 and 394 as to need of further development in design.

KIDWELL BOILER CO. has worked out the details of a header design which accomplishes this result, and in due time will offer such design to those of its clients whose conditions are such as to require a boiler of this type.

277. Many will quickly reply, "If the above is correct, why is it that so many of such boilers are in use, and that some large and prominent purchasers will consider no other?" Answer:—

Of all human tasks the hardest is to make men *think along new lines*. Therefore, precedent is one of the most potent factors influencing human acts. A pertinent illustration is that because European navies took up the Niclausse boiler (Sect. 245) the U. S. Navy did likewise, though any tyro in the art of boiler design can see that this is a wholly wrong as to constricted circulation, *if he studies it in light of proved technical principles*. But it is far easier to do what the multitude does than to undertake hard mental labor and assume the responsibility of creating or sponsoring new discoveries or improvements. From the times of Archimedes or Columbus down to this day, men who do such things encounter incredulity, then active hostility. "Short-sighted people, and that includes us all, fight against *every force that tends to make them better, richer and happier.** No one man will admit that this in his own case, but whoever is familiar with the facts of history recognizes the sad truth. Almost every invention of labor-saving machinery has been bitterly denounced by the workers. And has *eventually bettered* their condition."—Dr. Frank Crane, in *The Friction of Progress*. "Prof. Elihu Thompson has truly said: 'Publish an invention freely, and it will almost surely die from lack of interest in its development. It will not be developed and the world will not be benefited!' This leads up directly to the main point I wish to make. Industrial progress is gained only by *individual striving*. * * * *Almost every epoch-making invention was pronounced a failure at first*, and it is only the unconquerable enthusiasm of the inventor, and his steadfast ability to meet the financial and moral strain, that saves the idea to the industry."—A. S. Dwight, President's Inaugural Address, American Institute of Mining Engineers, 1922.

278. Read in Sects. 7, 10, and 14 the statements of Prof. Lucke, M. Bertin and Admiral Melville showing that today steam boilers are imperfectly understood even by men who are presumed to be most familiar with them, hence earlier and deficient types are bought, because better known than others which came later and are much superior.

279. It is precisely for this reason that the present book is written on different lines from its predecessors. It presents in a lucid way those facts necessary to an understanding of boilers

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*For example:—About the close of the reign of Charles the Second "An ingenious projector, named Edward Heming, obtained letters patent conveying to him, for a term of years, the exclusive right of lighting up London. He undertook, for a moderate consideration, to place a light before every tenth door, on moonless nights, from Michaelmas to Lady Day, and from six to twelve of the clock. His scheme was enthusiastically applauded *and furiously attacked*. The friends of improvement extolled him as the greatest of all the benefactors of his city. What they asked, were the boasted inventions of Archimedes, when compared with the achievement of the man who had turned the nocturnal shades into noon-day? In spite of these eloquent eulogies *the cause of darkness was not left undefended. There were fools in that age who opposed the introduction of what was called the new light as strenuously as fools in our age have opposed the introduction of vaccination and railroads, as strenuously as the fools of an age anterior to the dawn of history, doubtless, opposed the introduction of the plough and of alphabetical writing.*"—Macaulay's *History of England*, Vol. I, Chap. III.

As to the opposition to railroads see Chap. X of *The Life of Geo. Stephenson*, by Samuel Smiles; (Harper & Bros., New York,) or in the *Lives of the Engineers* series; (John Murray, London). The ludicrous arguments advanced to prevent Parliament issuing a charter for the first real railway undertaken in England may appear incredible, but not more so than those used in this country. In 1838 some young men in Lancaster, Ohio, petitioned the Board of Education for use of the school house to discuss the feasibility of railroads and telegraphs. The Board's refusal and its reasons follow:—"You are welcome to the use of the school house to debate all proper questions in, but such things as railroads and telegraphs are *impossibilities and rank infidelity*. These is no work of God and about them. If God has designed that His intelligent creatures should travel at the frightful speed of 15 miles an hour by steam, He would clearly have foretold it through His holy prophets. It is a device of Satan to lead immortal souls down to hell."—*Detroit News*.

The evil consequences of such mental lethargy are thus depicted by President Lowell of Harvard:—"Most people, and perhaps in a peculiar degree the American people, tend in the busy life of the world to save themselves from strenuous thought by *taking refuge in the opinions of their associates, of the men in like occupations, of the party or group to which they belong*. This saves some of them, indeed, from eccentricity and irrational extremes; but it does not absolve men from the responsibility for the correctness of their opinions or save the nation from the consequences of their errors. The fact that others make the same mistake is no excuse. Yet people who go with the prevailing current of opinion seldom feel any responsibility, still less contrition, when that current leads to wrong doing or disaster. Although men are by nature gregarious creatures they should not, like sheep, move under the simple impulse of the mass. Man has the ability to think for himself, to weigh reasons, to forecast in some degree the future, and to reflect upon the consequences of his acts. *In times like these* it is of vital importance that his responsibility for his individual opinions should be relentlessly asserted.

sufficient to enable one to determine what design will produce the *maximum returns on an investment.* If these facts are mastered, the conclusion above formulated will inevitably follow, and future development will surely proceed along lines in accordance therewith. Engineers today are fast realizing that fact so tersely stated by that most capable executive, Daniel Willard, president of the Baltimore & Ohio Rail Road:—"We must get greater returns from the things we buy," hence they are now seeking *facts and results,* and the search for them can have but one end—that above forecasted.

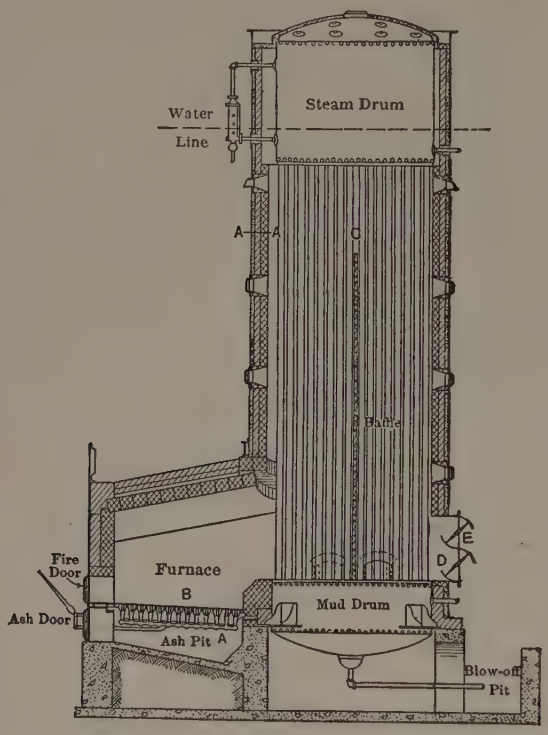


FIG. 92

280. This conclusion was reached by many far-seeing engineers decades ago, but the problem of producing a design to obviate these defects was not an easy one, nor until the appearance of the Kidwell Two-Flow Ring-Circuit boiler was there any complete and satisfactory solution. Many designs appeared, some worse than those their inventors hoped to displace, and but few of these have survived, and none of them solved the problem except in some detail, while the other defects remained or new ones were introduced. We shall reproduce several of these merely to point out in a brief way wherein they are improvements or the reverse.

281. Fig. 92 from Gebhardt's *Steam Power Plant Engineering,* shows a design which is simple and does away with the handhole and cap nuisance. These features are improvements. Some defects are, small water endurance surface, usually a restricted furnace volume; necessity of using a Dutch oven which while advantageous in certain cases is often objectionable in others; it primes badly; it momentarily reverses the circulation in the rear bank if there is a sudden drop of pressure in the upper drum; its tubes have to be pulled through the tube sheets, which is objectionable for reasons given in Sects. 152 and 153, and it has large flat tube sheets which may develop trouble as the inner tubes are in compression and outer tubes in tension, which is conducive to leaks. This requires explanation. Also see Fig. 135D, page 146.

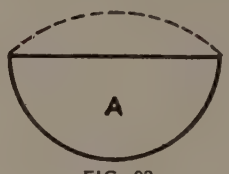


FIG. 93

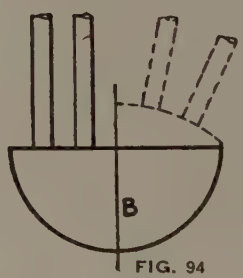


FIG. 94

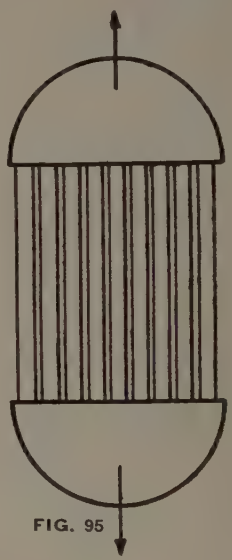


FIG. 95

282. If a vessel as shown in full lines in Fig. 93 is subjected to internal pressure the flat top will bulge out as shown by the dotted lines. If tubes are inserted as in left hand side of Fig. 94 they will, after the pressure is applied internally, take the position shown by the dotted lines. To bring the sheet back to its original position a thrust equal to the internal pressure must be applied. If sufficient thrust is applied by the tubes and they do not loosen up in the tube holes, the sheet may be brought back to position in that way. Now, connect two vessels like A and B with tubes as in Fig. 95, and apply an internal pressure. The vessels tend to move in the direction of the arrows, and the force trying to pull them apart is equal to the internal pres-

sure per square inch multiplied by the sum of the internal areas of all the tube cross sections. But, to hold the tube sheets flat, the middle tubes must exert a thrust on those sheets as above shown, hence *those tubes are in compression.* Therefore, the outer tubes must resist not only the total steam pressure trying to push the two vessels apart, but the thrust from the inner tubes as well. Therefore, in this arrangement the tension on the outer tubes is far greater than would exist in a water leg type such as Fig. 67, hence the increased *liability of distortion, leaks, or rupture.*

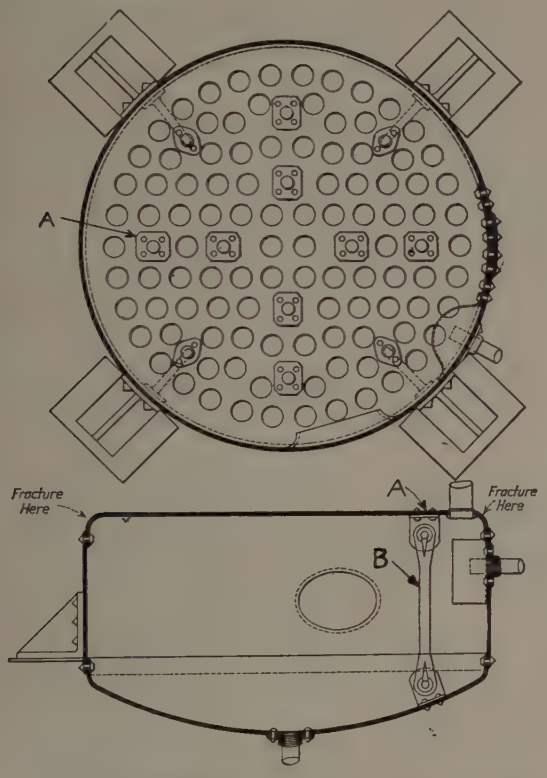


FIG. 96. SHOWING POINTS OF RUPTURE IN LARGE TUBE SHEET

283. As soot accumulates on the bottom sheet, and when wet is highly corrosive, such corrosive action on both sheet and tube ends is frequent and needs watching.

284. The mud drum is of large volume and will precipitate sediment better than possible in any header and cap type. Feeding into this drum is objectionable, however, for reasons given in Sects. 134 to 137.

285. Structurally, the large diameter of the drums, heads and tube sheets sacrifices one advantage of water tube construction, a cardinal principle of which is to avoid drums of large diameter. Such big heads and tube sheets often need staying, and different makers use diverse ways of doing this. Fig. 96 shows a method of one builder, and is taken from *Frozen Safety Valve Causes Boiler Explosion* in *Power,* Feb. 3, 1920. Twelve braces B were used and located as at A. The drum fractured at the places as marked because of overpressure. In making an analysis of this case the above article says:— "In boilers of this character the tubes nearest the fire are hottest and those on the opposite side of the baffle are comparatively cool. Consequently, the front tubes tend to bow or buckle and pull up the tube sheet. There would also be a tendency to tilt the top drum in a direction

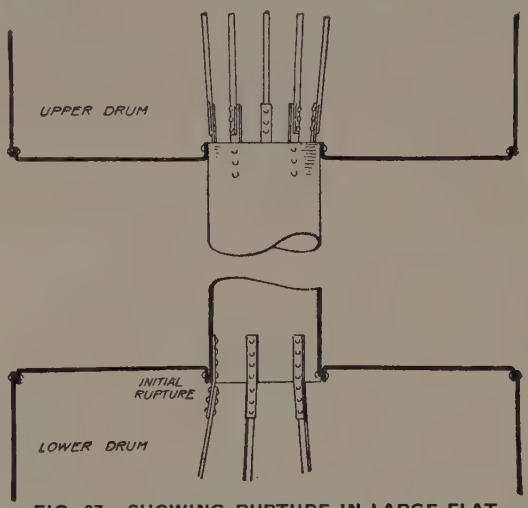


FIG. 97. SHOWING RUPTURE IN LARGE FLAT TUBE SHEET

opposite from the furnace, and push down the lower tube sheet on that side. In other words, there would be a severe twisting movement with considerable leverage on the lower tube sheet, straining the metal particularly at the knuckle of the flange. Poor circulation would aggravate and prolong this action." While we concur as to the *results* above said to be produced, we disagree as to the reason. Refer to Fig. 7 and Sect. 53, etc., and it will be clear that the statement that the rear tubes are cooler than the front ones because of the implied difference in temperature between fire box and rear bank, is not necessarily correct. The real reason will be explained in Sect. 287.

286. Figs. 97 and 98 are from *Boiler Explosion In East Chicago Kills Seven,* in *Power,* March 12, 1918, and show how a boiler of this general

type, containing a large central tube supposed to act as a down-comer, failed in the tube sheets, thus confirming the liability of such sheets to cause trouble. A possible reason for the tendency of such designs to fail in the lower drum

FIG. 98. SHOWING HOW TOP SHEET OF LOWER DRUM IN FIG. 97 WAS DISHED UPWARD DURING THE EXPLOSION

may be the excess pressure at the bottom due to the hydrostatic head. Thus, if the tubes were 24 feet long with 12 inches of water above them, and the bottom drum 4 feet in height, the hydrostatic pressure at 125 lbs. gauge would be 11.1 lbs. per sq. in., so the pressure on the bottom sheet would exceed 136 lbs. We do not know that this is taken into account by inspectors, but it should not be ignored. The upward dishing of the original flat sheet, as shown in Fig. 98 clearly proves the intensity of the force causing this explosion.

287. That the front tubes of such boilers do buckle and produce the results stated in Sect. 285 is quite well known. Fig. 99 illustrates the fact better than any description. The reason for this, however, is that steam bubbles tend to adhere to metallic surfaces. Place a pan of water toward the back of a stove, and let it heat gradually. Notice how the bubbles adhere to the metal instead of rising. Refer to footnote, Sect. 35. When a boiler tube is vertical the bubbles of steam will tend to keep in contact with, and slide upward along the tube wall. This does two things. First, it causes a layer of steam to act like a lining on the inside of the tube wall, which in turn prevents the heat from getting through to the water, so that the effect is identical with that on the top of Fig. 1, therefore, the tube overheats, buckles, and fails, as in Fig. 99. Secondly, this prevents proper emulsification of the steam and water. It is for this reason that inclined tubes circulate better than vertical ones because the steam bubbles are easier scrubbed from the tube surface by the flowing water.

"Steam has a natural tendency to cling to heating surfaces. Therefore as the steam cannot rise through the superincumbent water as fast as it is generated, it accumulates on the heating surfaces, *forming a film between the heated plate and the water,* causes inflation of the water, which rises to a greater height in the boiler than due to the natural position of the water and steam. In such case the quantity of water indicated by the water gauge is greater than the actual quantity in the boiler."—Hutton, *Steam Boiler Construction,* p. 100. Compare with McDermet's statement in Sect. 215. Such film of steam causes overheating of the tubes.

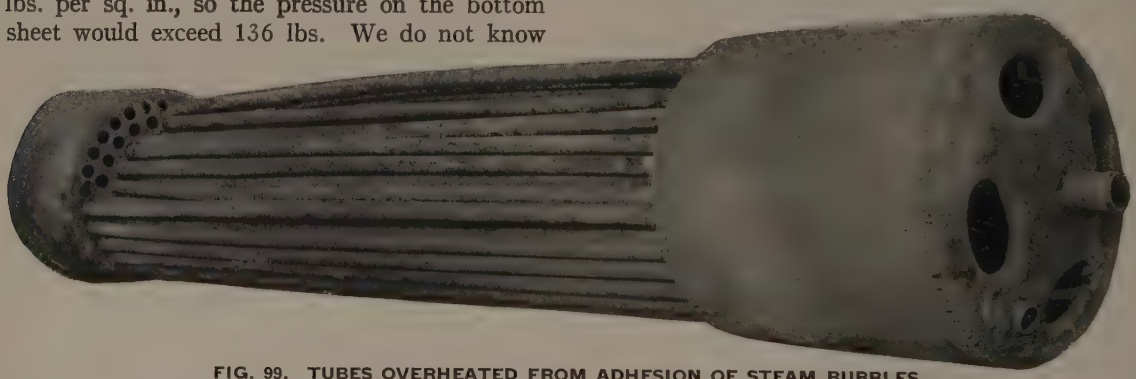


FIG. 99. TUBES OVERHEATED FROM ADHESION OF STEAM BUBBLES

288. The claim for this design that the liberal distance between water line and outlet prevents priming is not substantiated in fact. Read Sects. 84 to 87, and refer to Fig. 44, then note that in case of a sudden drop of pressure in the upper drum each tube then acts like the gun in Fig. 43 and ejects with great velocity all the steam suddenly formed, which shoots up through the steam space and violently strikes the top

of the drum, hence causes wet steam. With all the tubes so spouting severe priming is inevitable. This is intensified by the very limited water endurance surface. See Sects. 78 and 79. Further, the water line is subject to distortion, and the gauge glass, as usually connected, does not indicate the average water level, as shown in Figs. 9 and 100.

289. The first 50% of heating surface in the up-comer side absorbs 85% of all the heat taken up by the boiler, leaving 15% to be absorbed by the down-comer tubes. See Fig. 175. Therefore, in any case where the heat of the liquid is less than 15% of the total, some steam may form in the rear bank of tubes and be swept into the

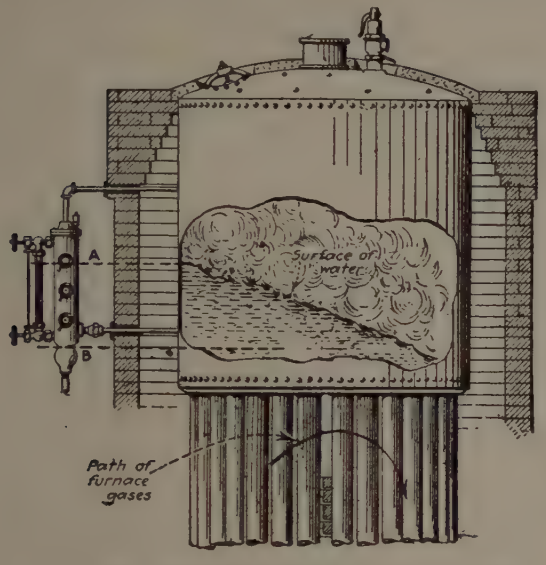


FIG. 100. SHOWING DISTORTED WATER LINE

mud drum and then up into the front tubes to join the fresh steam generated therein. But, in case of a sudden drop in pressure in the upper drum this steam in the rear bank will expand upward like a suddenly released spring, and project the water upward with it, and thus reverse the direction of the circulation.

It has been strongly urged against this design that the steam formed in the rear bank *tends to rise, hence impedes the circulation.* Such objection is groundless. This will be apparent from Sect. 55 and it is only fair to state the facts. The only time when trouble will result from this cause is *when the pressure in the top drum drops quickly*, in which case the water in *both tube banks* will be thrown upward. Such deficiency is by no means confined to this design, as shown throughout this book.

290. The gas courses in this design are vertical, as are the tubes, and such gas may be affected by "laneing," so that it may not all be brought into contact with the tubes, hence may go out at a higher temperature than in many other designs, which action is opposed to high economy. Also, the gas and water flow in the rear tube bank are contrary to Sect. 132.

291. It is also sometimes claimed for this general design that its draft loss is so much less than in other boilers that it needs only a short

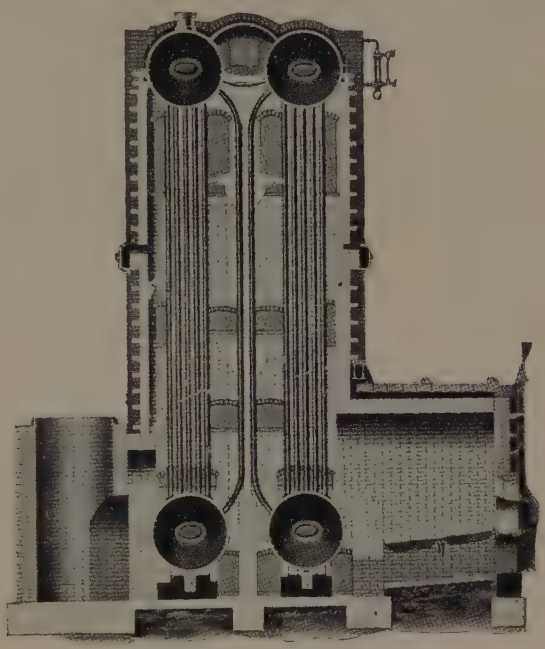


FIG. 101. A VERTICAL DESIGN

stack. If such is so, it is a deficiency instead of a merit. "The velocity at which gases pass over the heating surface will be the factor that will be used for increasing the capacity of boilers. A boiler that has its heating surface arranged in such a way that the gas passages are long and of small cross section is more efficient than a boiler in which the gas passages are short and of large cross section."—Bulletin 18, Bureau of Mines, p. 24; also see Sects. 35 and 36. To secure such result requires ample draft and a short stack cannot produce it. In the design above discussed the gas courses are shorter and of larger cross section than usual, hence a shorter stack may suffice, but loss of economy must result. See Sect. 662.

292. An advantage of this type is that it is easy to build, does not require such extensive

shop equipment as needed for most other types, and can therefore be *sold at a low price*. Consequently, where fuel is cheap and economy secondary, as usual about saw mills, it has been extensively used.

293. Fig. 101 from catalog of Harbison-Walker Refractories Co. shows a design in which each of the above named defects, except large flat surfaces, is duplicated or intensified, and some worse ones added. This is a revival of the ancient scheme shown in Fig. 124. The number of tube banks is reduced to two, which are cross tube to the rear bank, then down that bank, but for the same reason as shown in the discussion of Figs. 103 to 105 it fills the front top drum, and causes both steam and water to flow through the upper steam tube to the rear drum, thus causing priming and a badly fluctuating water line, all as in Fig. 105. This design is often fed through the mud drum, which is objectionable as shown in Sects. 134 to 137.

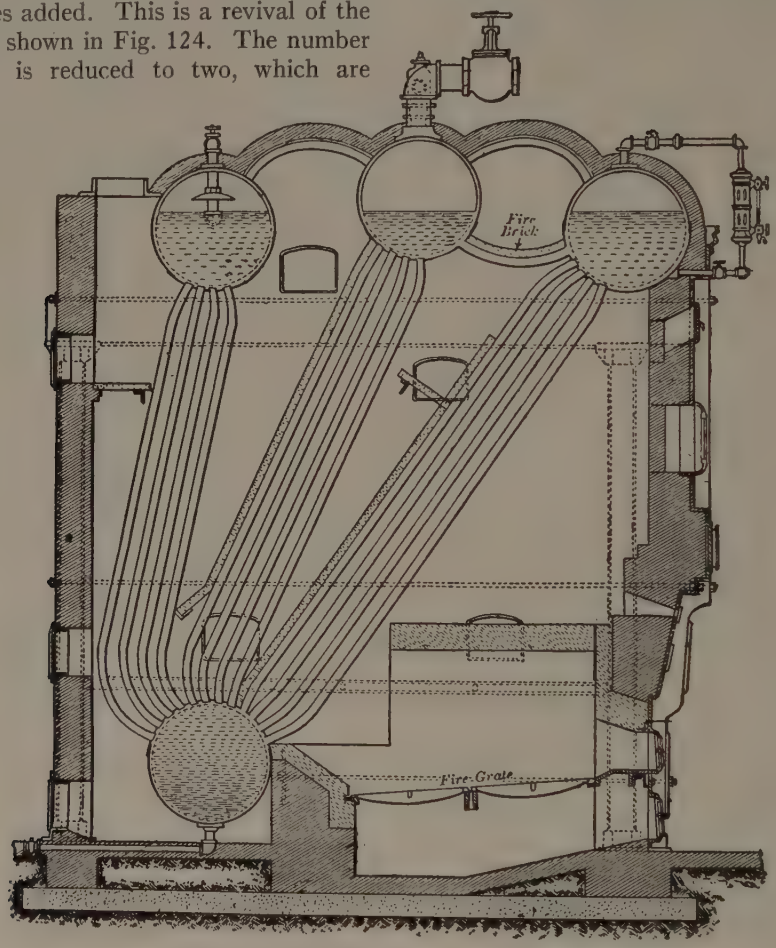


FIG. 102. A DESIGN WHICH ELIMINATED HEADERS, HAND HOLES AND CAPS, AND PROVED THE SUPERIORITY OF CURVED TUBE BOILERS

placed vertically, and part of the tubes are straight. These tubes enter the drums through flat seats pressed in the cylindrical sheets as in Fig. 126, except here the flats are pressed separately for each tube hole. (By an error of the artist a straight horizontal tube connecting the lower drums on a level with their centers was omitted, but is always used in the actual structure.) The water passing up the front bank is supposed to flow through the horizontal

294. By far the most successful of these designs is shown in Fig. 102. While fought from every side with an intensity that has never been equalled, it gradually made its way to front rank, and to it is due more than to any other design the credit of proving that curved tube boilers are as to efficiency of capital superior to all others, and of squelching beyond resurrection the delusion that headers and caps are essential to good boiler design—an idea which, like Sind-

bad's "Old Man of the Sea," throttled progress and had to be killed off before true advance could be made. *The best evidence that this design marked the greatest advance of its time is that those who did most to try to kill it off were later compelled not only to acknowledge its excellence, but to withdraw the strictures they made on it and to join in the task of exploiting it!* That it produces reasonably good efficiency follows from the fact that its circulation is faster than that of header types, and Figs. 4 and 5 therefore show results in accordance therewith. Yet in this design the second bank of tubes absorbs about 20% of the total heat taken up by the boiler, hence it generates some steam which

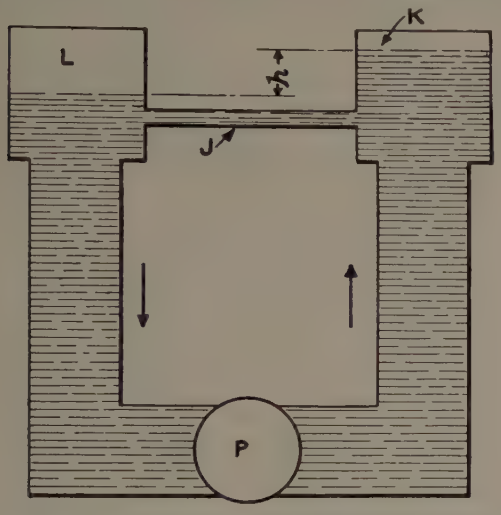


FIG. 103. ILLUSTRATING CIRCULATION IN FIG. 102

is swept into the mud drum, thence into the front bank of tubes, therefore the gas and water flow in this second bank is contrary to the law of efficiency stated in Sect. 132.

295. As the requirements of steam plants increased and higher ratings and dry steam became imperative, it was found that this boiler possesses other serious deficiencies, because the features essential for meeting present requirements were not known to its designers, as will now be proved.

296. In Fig. 102 the water is shown at the same level in all the drums, a condition which *cannot exist when the boiler is operating.* Rig up a model like Fig. 10 but with the proportions as shown in Fig. 103, in which P is a pump as before. The faster the pump operates and the greater the quantity of water, the higher the level K will become, as the head *h* necessary to force the water through J to cistern L must increase to correspond. If the pump be speeded up sufficiently the level K will overflow the cistern, instead of passing all the water through J.

297. Let Fig. 104 represent the water system of Fig. 102. Here the flow up B C is caused by the rising steam, and the water line in the cistern will be at an inclination as shown and further illustrated by Figs. 9 and 100. The specific gravity of the emulsion of water and steam in B C is so much less than that in A B that the shorter column A B balances the longer column B C. But in the rear bank there is only water and no steam, hence the specific gravity of this column is still greater, hence the level is still lower by the amount *h*.

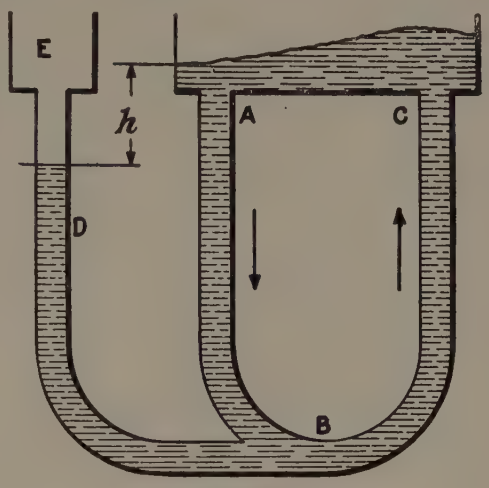


FIG. 104

298. Accordingly, the actual condition inside this boiler when operating is shown by Fig. 105. The volume of water passing up the front bank is such that to drive it over through the tube E requires a head greater than possible in the front drum, hence it fills that drum up to the level of tube F, and a mixture of water and steam is sprayed into this drum, hence severe priming results. The water level in the middle drum will be where shown, and in the rear bank the water will be down in the tubes as at B B, and the rear drum contain no water. The distance K in a boiler of *average size is frequently 3 feet,* and in large boilers has been found to be from 5 to 10 feet! For corroborative evidence we cite the following facts:—(a) Refer to Sect. 310 and the statement of D. S. Jacobus quoted therein. (b) The rear drum of this design is often burned and bagged whenever the tiles behind the second tube bank are displaced and such burning

would be impossible if the drum contained water. This is recognized by Jacobus so that in Fig. 111 he inserts the baffle marked 27 to project this drum. The steep angle of the baffles behind the first two tube banks increases the liability of the tiles to slip out of place, especially if even

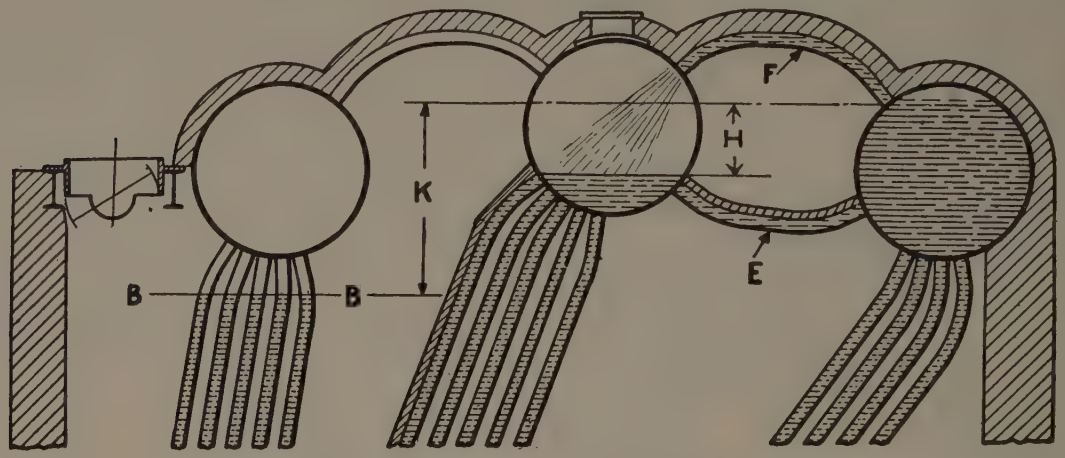


FIG. 105. SHOWING VARIATION OF WATER LEVELS IN DRUMS OF FIG. 102

a slight gas explosion occurs in the furnace, and this augments the danger of burning the rear drum. See Sect. 300. (c) Experiments with exploring tubes have repeatedly confirmed this fact, as any one may do by installing a water gauge on each of the three upper drums and comparing their indications.

299. If this boiler operates an engine working intermittently, like a rolling mill drive or mine hoist, and firing slacks during the operating period, the water in the front drum in Fig. 105 will drop, while that in the rear drum will rise, then all this will again shift when firing begins, so this seesawing will be endless. Besides the obvious objections to this, it also reduces the fuel economy. See Sect. 511.

It must particularly be realized how this great difference in level affects the accuracy of fuel tests. In these the operator makes a flying start when the boiler is steaming, then marks where the water stands *in the water glass* at this start, without realizing that in the rear bank *the water may stand 3 to 6 feet or more below that point!* At the close of the test he slacks down so everything will be quiet and enable him to check the final water line. *But then the water in the rear bank will rise to about the level in the glass, and the difference in the volume of water between the initial and final state will be credited to the boiler as having been evaporated, whereas it was not evaporated but was used to make up the above stated difference in level!* This introduces an error the effect of which is greater in proportion as the test period is shorter.

300. Failure of Drum Due to Overheating. That the statement above made in (b) is correct will now be shown. In *Power,* p. 27, Jan. 4, 1921, Fig. 106 is given, illustrating how a certain drum bulged and cracked because shavings dropped on the drum by the draft had ignited and caused the overheating. This case brought out another article in *Power,* Feb. 15, 1921, p. 279, under caption *An Unusual Boiler Failure,* as follows:—

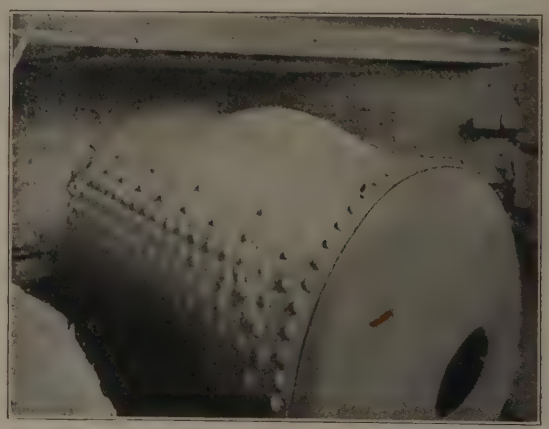


FIG. 106. DRUMS RUPTURED BY OVERHEATING

"In the Jan. 4 issue of *Power,* reference is made to the distortion that took place in the upper part of the shell plate of a water tube boiler. *The failure is termed unusual, but as a matter of fact it is quite common.* The photo-

graph reproduced in the article could be used to illustrate similar damage that has resulted recently to 10 or 12 boilers in widely separated localities, due to the same cause.

"Investigations that have been made following accidents of this description do not indicate that the overheating of the shell plate was the result of the ignition of soot or other deposit that had lodged upon the upper part of the boiler, but rather to the continued high temperature of the flue gases.

"In one plant, where 6 boilers were affected in this way, it was found that no serious difficulty had been experienced during the time the boilers were being operated under normal load conditions. An enlargement of the shop had caused an increased steam consumption, so high duty stokers were installed under the boilers to provide the additional evaporation without increasing the boiler capacity. The soot that had accumulated had been removed each time a boiler was cleaned. * * * There is no doubt that the upper part of each boiler, where exposed to flue gas temperature, was reasonably clean when the bulging took place, so the difficulty could be attributed directly to the high temperatures resulting from the overloaded conditions.

"At the rear end of a water tube boiler with a level drum, the circulation of the steam is not sufficient to prevent the *shell plate* from overheating when it is exposed externally to high temperatures. * * * * All parts exposed to the products of combustion should be protected by water; if not, they should be insulated from the gases.

"This * * * * of course, would not apply to superheating elements, because the circulation of steam in superheaters is *rapid and positively directed*, so that the steam can be depended upon to prevent a dangerous increase in temperature in the walls of the superheater tubes unless the external temperatures are abnormally high."

It would appear from this account that the author of it did not realize the exact reason for this overheating, but Sects. 298, 299 and 366 will make it clear. These cases merely prove once more the danger of *assuming* that a drum contains water *when in fact it does not, and CANNOT when the boiler is operating at reasonably high rating, as already proved!*

301. Originally the water column was connected to the front drum as in Fig. 102, but because the water either filled this drum, or at even low loads bobbed up and down with every variation in the firing, the water in the glass fluctuated so that its indications were ambiguous or misleading, hence later the connection was made to the middle drum in which the fluctuations are less violent. This, however, gives no indication as to when water is passing over through tube F in Fig. 105, but that it does pass is further proved by frequent presence of mud in this tube. Further, the long connecting pipes between drum and water column have proved to be objectionable.

302. The vital necessity of adequate water endurance surface is shown in Sect. 78, yet from Fig. 105 it is obvious that the *effective* water endurance is only that in the middle drum and rear tubes, or about 40% of the *apparent* surface in Fig. 102, which is another almost fatal defect and shows why this boiler needs such careful attention as to feeding in order to prevent low water.

303. Rear Tube Bank Now Falling Out of Use. In consequence of the many troubles due to widely fluctuating water level and other reasons above explained, and additional ones given in Sect. 311, this rear bank arrangement is now being abandoned in Europe. See Figs. 115 and 116, the former of which shows the arrangement now advocated by a concern in England which previously made and offered the design in Fig. 102. But the Detroit Edison Co. did the same thing about 13 years ago and has continued that policy ever since. It is also significant that the great Gennevilliers Super-Power Station just built at Paris has also omitted this rear tube bank. See *Power*, August 1, 1922.

304. This design has been noted as priming much more readily than many other types. The reason for this will now be shown. In case of a drop of pressure in the middle drum to which the steam outlet is usually connected, all the water in the mud drum and the tubes below immediately liberates heat which instantly generates steam (Sects. 83 to 86). This expands like gas in the gun, Fig. 43, and ejects the water violently up into the drum just as done by Figs. 92 and 101. The tubes F, Fig. 105, join in this action and with this multitude of geysers operating extremely wet steam is unavoidable. Now compute as in Sects. 98 and 99 what this costs the owner, and it will be clear why anyone who values fuel cannot tolerate such loss, and why no boiler which primes is a good investment, and particularly so if it delivers *dirty steam*. See footnote to Sect. 534.

UNITED STATES PATENT OFFICE.

JAMES P. SNEDDON, OF BAYONNE, NEW JERSEY, ASSIGNOR TO THE BABCOCK & WILCOX COMPANY, OF BAYONNE, NEW JERSEY, A CORPORATION OF NEW JERSEY.

WATER-TUBE BOILER.

1,318,509. Specification of Letters Patent. Patented Oct. 14, 1919.

Application filed July 8, 1916. Serial No. 108,093.

Fig. 108.

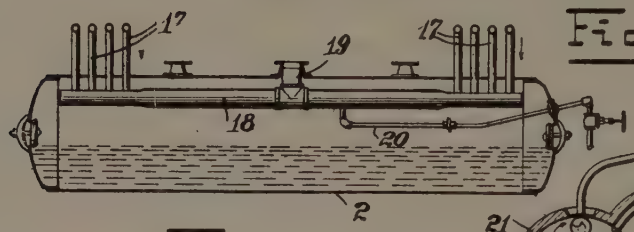


Fig. 109.

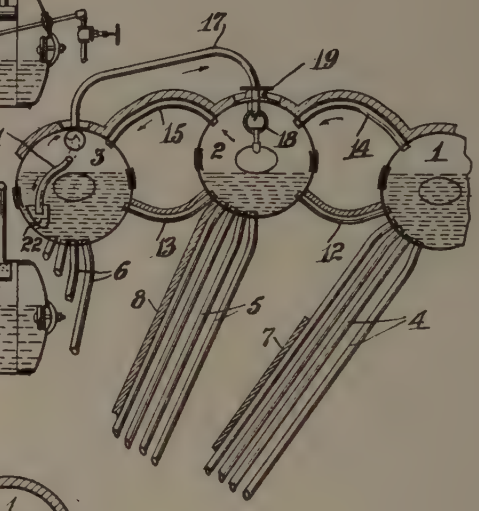
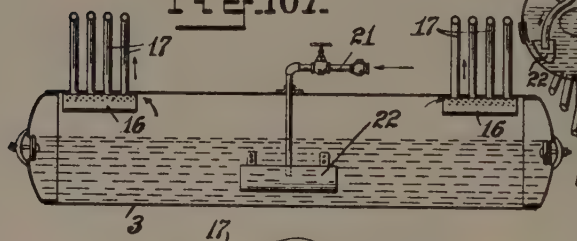


Fig. 107.



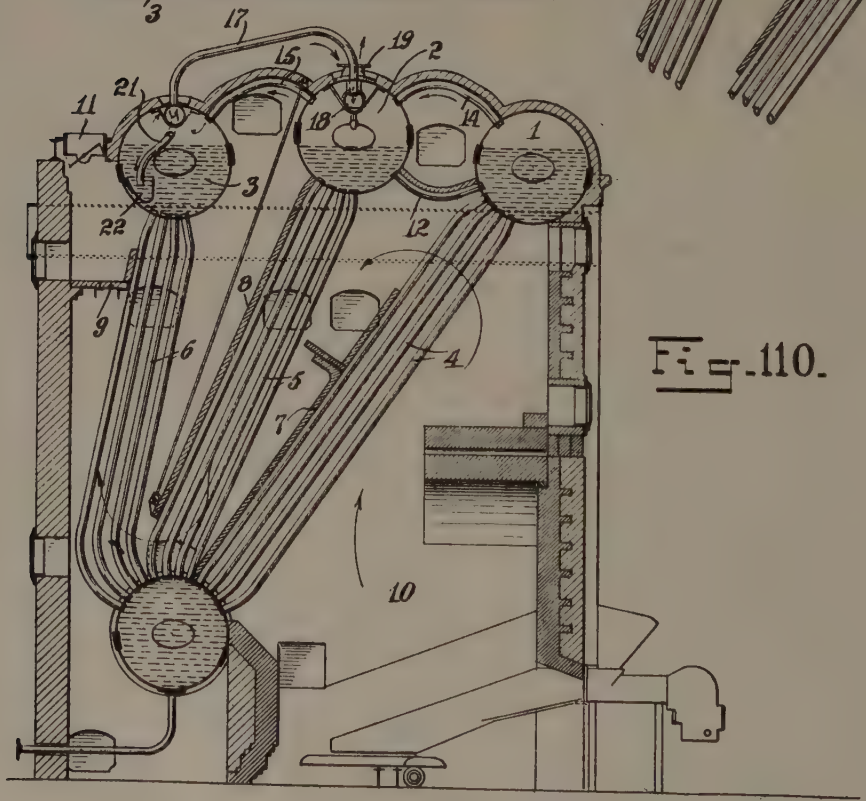


Fig. 110.

FIGS. 107 TO 110. SNEDDON'S SCHEME FOR REDUCING PRIMING IN FIG. 102

305. Attempts to Reduce Priming. Proof that this design primes badly is afforded by the schemes put forth to cure this evil. We shall present only two, both by leading officials of a concern actively engaged in marketing this type, so it is reasonable to assume that they knew what they were doing, so were not prescribing for an imaginary trouble.

306. Figs. 107 to 110 show one of these, concerning which the inventor says:—"The general object of the invention is to provide a construction which will prevent or reduce priming." Note that in Fig. 102 the steam is taken out of the middle drum. This invention proposes to convey the steam from the middle drum into the rear drum through tube 15, then collect it through perforated pipes 16 which turn it into outer cross pipes 17, which pass through top of the upper drum and terminate in a pipe 18 in that drum. This is connected to the usual outlet 19, and provided with a drain pipe 20.

307. Any mechanic will realize that to make these tubes 17 tight where they pass through the drum shells, and connect to pipes 16 and 18 is an impossible task without resort to methods too expensive and complicated to be tolerated. The scheme assumes that when steam passes out of tube 15 the entrained water will drop out, and only steam enter the tubes 17. This is not correct, since the water is emulsified with the steam and will pass out with it, as proved by similar devices which have not made good. Fig. 122 shows one.

308. The inventor further states:—"This invention is especially adapted for boilers *which are in service* and have a steam outlet connection from the middle drum, as the steam may be led from the rear drum without altering the steam connections leading from the boiler." This admits that the boilers already installed do prime so excessively as to need such device.

309. As this remedy failed to meet the requirements another was attempted, as shown in Figs. 111 to 114. In this the inventor raises the rear drum to the level of the middle drum, *thus admitting that the standard arrangement is deficient.* He too conveys all the steam to the rear drum, and collects it into a long pipe 24 with perforated ends 25, and terminating in a steam outlet 22 on the rear drum. To assist the steam passing through tubes 9 to drop the entrained water he crowds them together so that none enter the outside quarters of the drum length, which is done to increase the distance from the tube ends to perforated entrance 25. This involves the same fallacy above pointed out, namely that emulsified water will not be carried along with the steam. Further, crowding the tubes so close requires a thickness of drum plate impracticable in any actual case, hence this device has not come into use, nor has any other scheme which overcomes the serious priming in this design yet made its appearance.

310. Note that in his patent application the inventor further makes the statement printed opposite Fig. 111, which confirms what was proved in the discussion of Figs. 104 and 105 *and is therefore authoritative!* This explains why he introduces the baffle plate 27 in Fig. 111 to protect the drum from overheating and bagging which occurs as stated in Sects. 298 to 300.

And it also introduces two more extremely serious evils which are explained in the last half of Sect. 321.

311. Other designs have copied from Fig. 102 the feature of a stand pipe or rear bank placed behind the main circuit as in Fig. 102, but in these also the water line is as per Fig. 104, hence the gauge glass will fluctuate with every change of load, and the danger of burning and bagging the rear drum always exists. See Fig. 143. Further, as a feed heater this arrangement is deficient in that the water in it is so nearly stagnant that it has not sufficient velocity to sweep along the precipitates which drop on the surface of the bends below, instead of being swept to the mud drum as occurs in the Kidwell boiler, for which see Sect. 529. These supplement the reasons given in Sect. 303 why this general arrangement is going out of use.

312. Note that in Fig. 109 a row of tubes is inserted between the middle and rear drums so as to reduce this trouble. Here again the head of water forcing the flow will be insufficient unless the water in the middle drum is carried at a height which will greatly decrease both the water endurance surface and steam space in this drum, hence this scheme also is practically ineffective.

313 In large boilers two or three circulators are sometimes placed between the front and middle drum, as 10 in Fig. 111. Even then the head necessary to cause the flow is such that the water will continue to build up in the front drum. This is shown in Figs. 115 and 116. The former is a British design, and the latter a German boiler shown in *Siemens Zeitschrift,* Oct., 1921, and reproduced in *Power,* Feb. 7, 1922. Both are reversions to an early form of Fig. 102

UNITED STATES PATENT OFFICE.

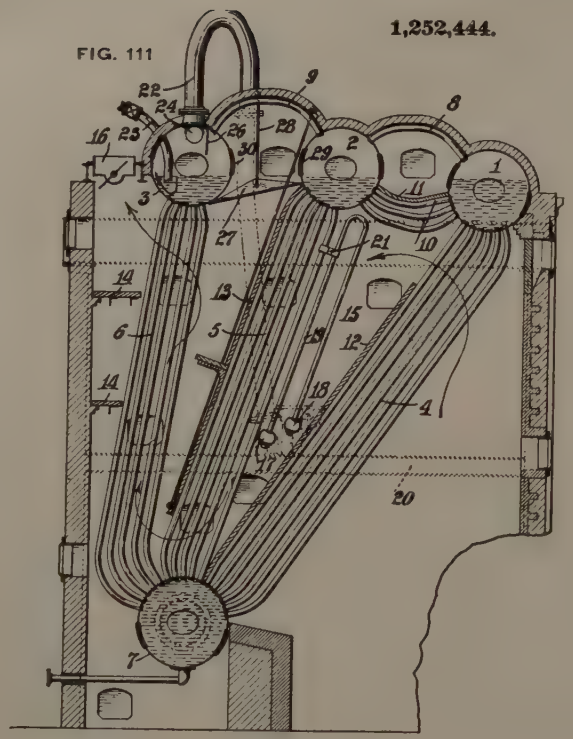
DAVID S. JACOBUS, OF JERSEY CITY, NEW JERSEY, ASSIGNOR TO THE BABCOCK & WILCOX COMPANY, OF BAYONNE, NEW JERSEY, A CORPORATION OF NEW JERSEY.

STEAM-BOILER.

1,252,444. Specification of Letters Patent. Patented Jan. 8, 1918.

Application filed April 7, 1917. Serial No. 160,369.

FIG. 111



Extract From the Inventor's Patent Specifications.

"As the density of the water in the rear bank is nearly constant, on account of the cooling action of the feed water introduced into the rear drum, *the water level in the rear drum will fall to such an extent that there will be no water in the rear drum, at high capacities, other than the feed water which flows through it.*"

FIG. 112

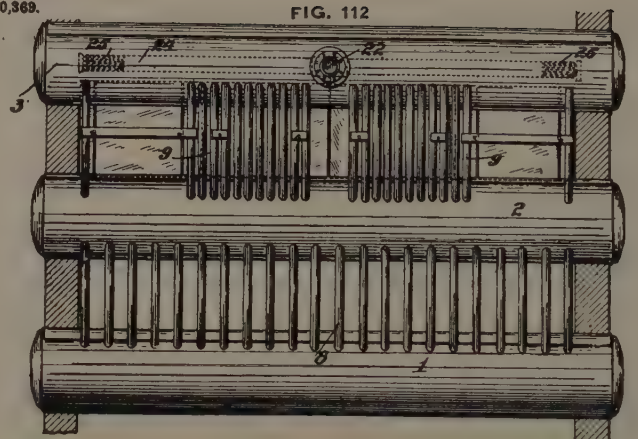


FIG. 113

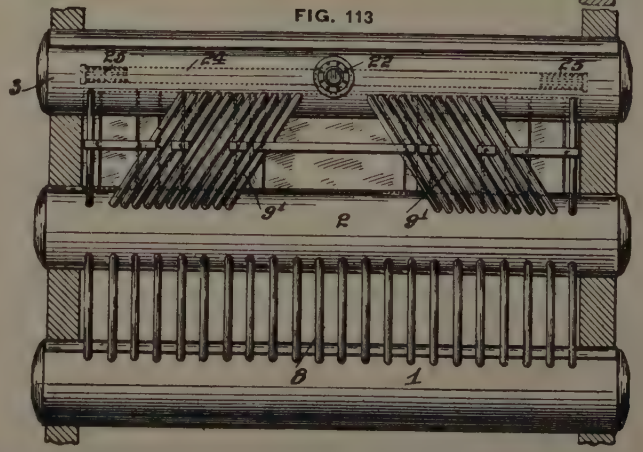
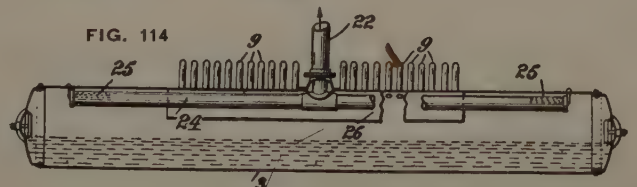


FIG. 114



FIGS. 111 TO 114. DEVICE BY DR. D. S. JACOBUS, INTENDED TO REDUCE THE INTENSITY OF PRIMING IN FIG. 102

which did not contain the rear tube bank now used. Note that Fig. 115 has 5, and Fig. 116 has 7 submerged tubes connecting the top drums. Yet neither arrangement can hold the water in the two drums at even approximately the same level. Proof:—In Fig. 115 three of these tubes have their entrance *above the water line as shown,* hence are useless unless the water rises above them when the boiler is steaming. Fig. 116 shows even more heroic treatment, as there are no top steam conveying tubes! In consequence, as steam accumulates in the front drum it not only prevents the water from rising so as to fill this drum, but drives it downward until

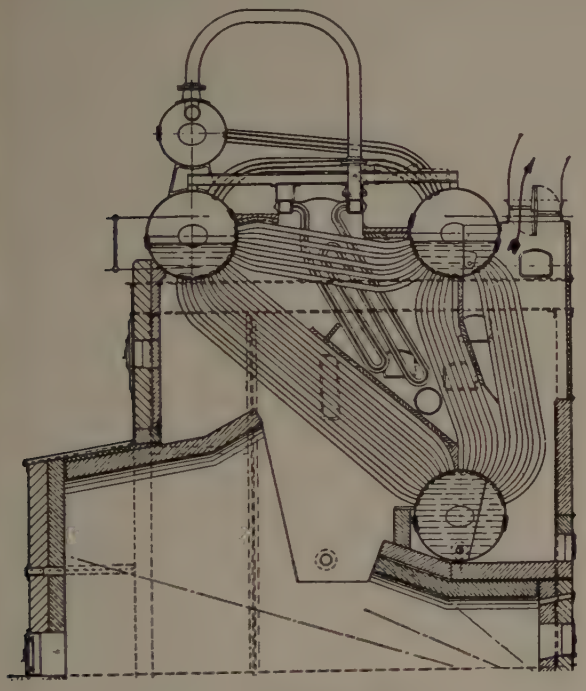


FIG. 115. ENGLISH DESIGN

it uncovers one or more rows of the cross-over tubes so as to permit the steam to pass through them. Evidently the steam will be discharged into the rear drum in spasmodic gulps, hence be very wet.

314. We have noted in sundry cases that when such tube arrangements are used the velocity in the lower tubes is always less than in the upper ones so that if mud is present it gathers in the lower tube and causes it to burn. Therefore, this general scheme is only a slight palliative instead of a cure, and the original deficiency remains unchanged.

But if this arrangement could be made to accomplish the purpose desired, it would bring in another evil as serious as the one it is intended to cure. It is obvious that the less the resistance to circulation in the *front bank* of Figs. 102 and 105 the greater will be the drop in the water level in the *rear bank,* which will increase a feature already fraught with serious danger. This is precisely what happens in Fig. 143.

315. Particular notice should be taken of the supplementary drums over top of Figs. 115 and 116. *These are open confessions that both boilers prime so badly that such drums are essential as water and dirt catchers! The use of such extra drums has now become standard practice in Europe,* as stated in Sect. 537, which fact brings out strongly the superiority of the Kidwell boiler as to the features shown in Sects. 513 to 517.

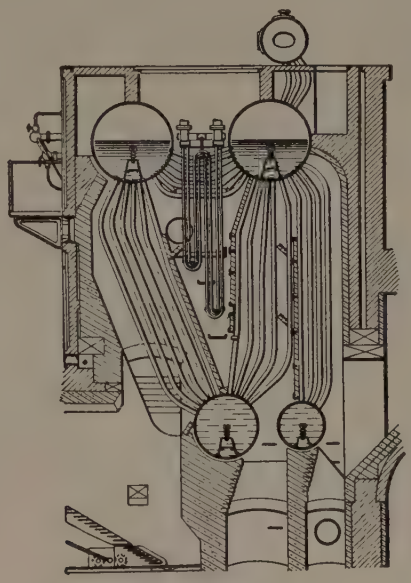


FIG. 116. GERMAN DESIGN

316. Of recent years some boilers like Fig. 102 have been put out with the baffles arranged to produce 4 or 5 gas passes. This is done by placing tiles behind the second or third row of tubes from the front, so as to make two gas passes through the first tube bank. Besides greatly increasing the draft loss through the boiler this scheme largely augments the danger of burning out tubes. The great amount of steam generated in the tubes toward the front causes the rear part of the tube to be filled with steam or foam like Fig. 1. While such tube can easily absorb all the heat applied to it by the flowing gas, it cannot at high ratings absorb the large additional amount radiated upon it by a

white-hot tile, hence overheating occurs precisely as pointed out in Sect. 264. Where the above described method is used it is not infrequent to find the tubes overheated and burnt even though entirely free of scale. See Bancel's remarks near end of Sect. 249.

317. A contributing cause to this result will now be explained as it is seldom if ever realized. In Sects. 53 to 57 it is shown that all heat absorbed by the down-comer ultimately reappears in the up-comer and helps to generate steam. Therefore, while the second tube bank of Fig. 102 generates some steam, this is swept into the front bank so that the final result is that *all steam generated in this boiler passes through the bank of tubes exposed to furnace temperature!* Nor is it otherwise different in horizontal types like Figs. 35, 86, 102, etc.

In Sects. 475 to 481 it is shown how this fact limits the maximum safe rate at which such boilers can be operated, and why they cannot even approach the Kidwell boiler as to safe overload capacity. And if "back boiling" or reversal of circulation in the back tubes of the first bank in Fig. 102 occurs, as some maintain that it does, *this augments the danger of overloading the front tubes because they must then handle all the additional heat swept down by the rear tubes,* in which case the above findings will be intensified to the same degree.

If now a baffle be inserted in the first bank of tubes in Fig. 102 it is clear that the tubes in front of it will be compelled to generate more steam than before, hence their liability of burning is increased in proportion. See proof of this in Sect. 264.

318. Conclusions As to This Design. It follows that as to improving the speed of circulation; operating at higher ratings; eliminating headers, hand holes, caps, and complicated structural shapes; accessibility to every part of the interior; and general all-around ruggedness this type is superior to its predecessors. But it falls far short of providing for perfect circulation; does not produce its maximum water speed in the part of the circuit exposed to highest temperature and conveying the maximum amount of steam (Sect. 52); is deficient in true water endurance surface; fluctuates extremely as to its water level; and primes to a degree which insures a large loss of fuel. In consequence this design also is, in every case where good engineering and sound financing prevail, surely slated for retirement. Yet it deserves the credit of weaning away from some deeply-rooted erroneous ideas the minds of men willing to do their own thinking and act in accordance therewith. Thus while this design contains some vital deficiencies it has, like St. John, gone ahead and prepared the way for the more perfected design which will now quickly displace it.

319. Revision of the Design Shown in Fig. 102. After the preliminary literature showing the advantages and performance of the Kidwell Two-Flow Ring-Circuit boiler had been issued and had attracted considerable attention, one manufacturer soon advertised extensively that the boiler shown in Fig. 102 had been greatly modified and improved! A description of this revision is given in *Power,* April 19, 1921, and it is worth while to investigate the extent and effect of such revision. Fig. 117 shows the latest arrangement. It differs from Fig. 102 in the following particulars:—

320. The number of water circulating tubes between the front and middle drum has been increased, though whether this applies to all sections of this boiler is not stated. This arrangement is old, the futility of its shown in Sect. 313, and it has no effect whatever on preventing the rear drum from losing its water, but if effective at all it merely augments that trouble as shown in last part of Sect. 314.

The middle bank contains one tube more than the front bank, which recognizes the principle laid down in Sect. 52, but the arrangement still falls short because *the smallest area in the water circuit is not over the fire,* and the portion of it between the front and middle drum requires a large difference in level to drive the water through as shown in Sect. 58 and Fig. 105.

The tubes extending from back part of the center drum to the rear tube bank, to serve as a baffle support, have been inserted to protect the rear drum against overheating when this drum contains no water. This is a substitute for the baffle marked 27 in Fig. 111. The fact that it has been found necessary to incorporate this into the standard construction proves that the menace pointed out in Sects. 298(b), 300 and 310 is serious and must be guarded against. *Yet the remedy adopted stops short of protecting the tube sheet at the bottom of the rear drum where the danger is greatest, hence this grave danger still exists!*

321. Steam is now taken out of the rear drum instead of the middle drum as in Fig. 102. Great stress is laid on the claim that this *reduces*

or eliminates priming, which claim therefore admits that the old arrangement was very faulty as to priming, as shown in Sects. 304 to 309.

That the new arrangement will neither eliminate nor sensibly reduce priming is clear from Sect. 304. When the pressure in the upper rear drum decreases, the water in the rear tubes will be violently ejected just as occurred in the middle bank with the old arrangement. This is obvious but if proof is required Fig. 143 furnishes it. In this the steam is also taken out of the rear drum, yet this arrangement primes even though the tubes between middle and rear drums are claimed to dry the steam somewhat. In Fig. 117 there is no provision for such drying effect, hence here priming will occur to a greater extent than in Fig. 143. Further, the water flowing over the edges of the mud pan 22 in Fig. 110 is falling *through the steam just below the steam outlets*, according to statement opposite Fig. 111. This produces wet steam and is as inconsistent as Solignac's scheme in Fig. 272. Yet this is the least of the evils resulting from absence of water from this drum, since there are two others far more serious. The first is *that the feed water dropping on the hot drum sheet below causes a sudden localized cooling which may crack the drum sheet, and this danger is greater in proportion as the feed water is colder!* It is not to be assumed that this is an imaginary danger because drum failure by cracking from this cause has occurred.

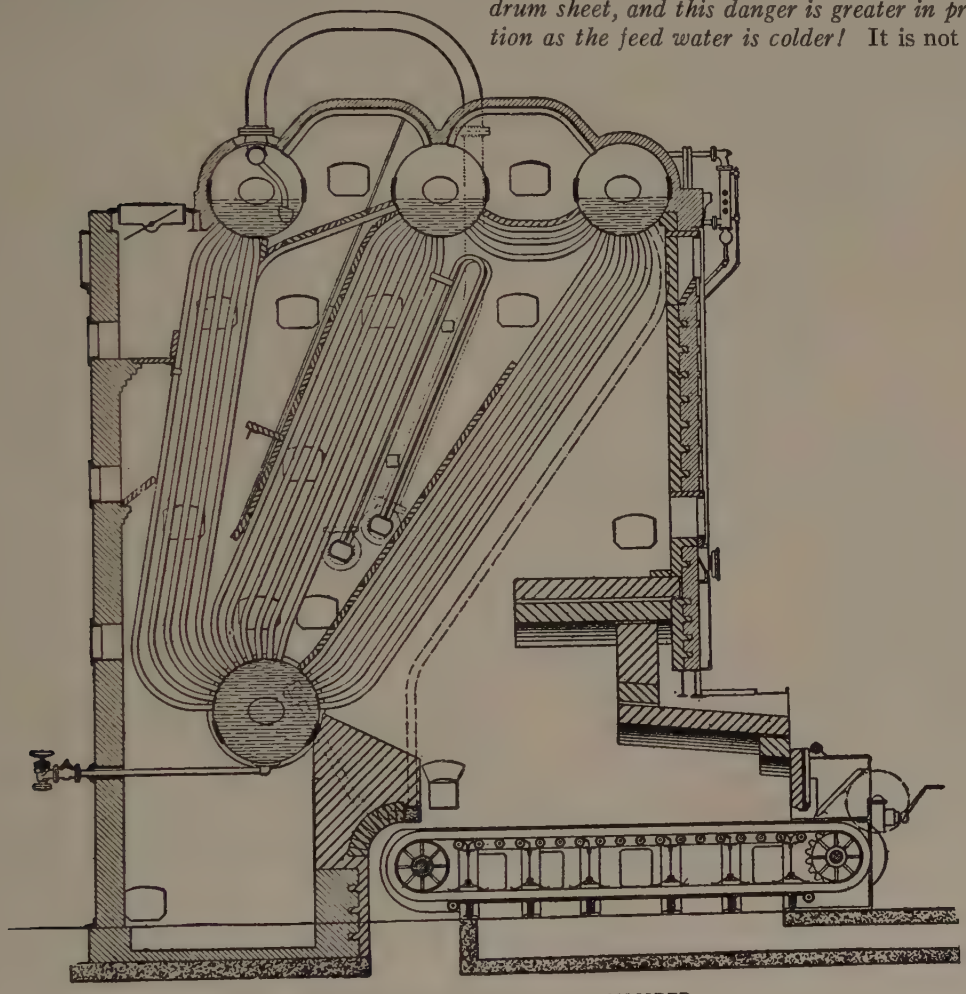


FIG. 117. SHOWING FIG. 102 REVAMPED

The other evil result is that along the line where the water strikes the sheet a ridge of scale often builds up, like a stalagmite, and besides increasing the danger of overheating and burning the plate it in time bridges across and closes the entrance to some tubes.

322. Stress is laid on the fact that:—"In battery settings special means of access for inspection of the inside mud drum heads *is standard in the redesigned boiler.*" In view of the fact that in the Kidwell boiler means of access to *all* blank heads of drums in the party wall of a battery was provided as shown in Sects. 430 to 432, and published long before the above described revision was heard of, this particular change illustrates the adage that "imitation is the sincerest form of flattery."

323. The above covers every new point of consequence, hence the amount of *eclat* with which this revamped design was brought out appears to be due to adroit advertising propaganda rather than to any improved results accomplished by it. The improvements are trivial and apparently more than counterbalanced by the disadvantages consequent on the changes. In the older forms provision was made, in various sections, for deeper grates than appear possible in the new sections, and this depth was advantageous when burning low grade fuels.

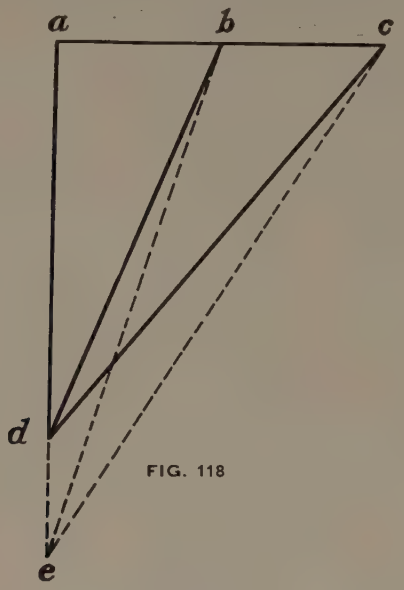


FIG. 118

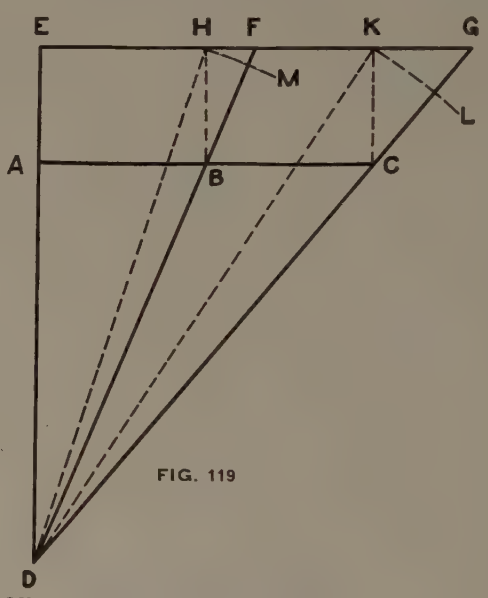


FIG. 119

GEOMETRICAL ILLUSTRATION OF TEMPERATURE STRESSES

324. Unquestionably the designs shown in Figs. 102 and 117 are superior to any two-header type as to provision for free expansion. Yet they still leave something to be desired. To insure *rigidity* a bridge or roof truss is built up of triangles tied together. *The same thing is done in both of these designs,* and such rigidity causes some severe stresses in the tubes. In Fig. 118 let *a, b, c, d,* represent a boiler when cold. Apply heat and raise the temperature of the boiler itself say 300 degrees. The drums *a, b, c,* being secured to the outer frame, cannot move apart to any appreciable extent, but the mud drum will move from *d* to *e,* and to make the figure easier to read we exaggerate the proportion of *de* to the other parts. The tube banks then take the position shown by the dotted lines. In Fig. 119 let A, B, C, D represent the original figure *a, b, c, d,* when the boiler is cold, and apply heat as before but not restrain the drums A, B, and C in any way. When expansion occurs we will have a new figure D, E, G, in which AE=*de* in Fig. 118. Erect perpendiculars at B and C, which locate H and K, then connect these two points with D, then HD=*be* and GD=*ce*. With radius KD strike an arc to locate L, and with radius HD locate M. Then figure E, D, K, duplicates figure *a, e, c,* which means that when forming figure *a, e, c,* stresses were caused in the tubes equal to that necessary to compress tube GD an amount GL, plus the amount caused by bending the tube through angle KDG, and similarly the middle tube will be compressed the amount KM, and be bent through the angle HDF. All this results from tying together the two triangles consisting of drums and tubes.

Consequently tube GD is in compression and helps to *rotate* the drum D, which brings a severe stress at the point where this tube enters drum D. This explains why tubes so frequently

crack at that point, and proves that while this design loses tubes far less frequently than common with header types, further progress is necessary before the above stated trouble can be wholly overcome. The changes introduced into the revamped design do not decrease this trouble.

In the design of the Kidwell boiler this deficiency has been completely eliminated, as shown in Sect. 539.

325. Modifications of This General Design. As usual when a design has proved even reasonably good, attempts have been made to utilize some part of Fig. 102 and exploit it as a *new type* of boiler. The usual scheme is to take two drums and its connecting tubes, stand these vertically, add a Dutch oven, make great claims as to simplicity and cheapness, and go after orders. These "designs," if they can be dignified by such name, usually are deficient in furnace volume, steam and water volume, and water endurance surface, and prime extremely. When two such elements are set side by side trouble occurs from unequal water levels, as in Fig. 101, and the water endurance surface, furnace volume, quality of steam, etc., are even inferior to those of the design shown in Fig. 102.

326. Fig. 120 from catalog of Harbison-Walker Refractories Co. shows a typical example. The extreme crudeness of it is apparent. It violates about every principle of good engineering so far as combustion and absorption of heat are concerned. The furnace is deficient in volume and bottles up the heat like in a crucible, so that little if any radiant heat can pass directly to the boiler. In consequence the brickwork will get excessively hot and need frequent repairs. In the Pennsylvania coal regions, where this type is mostly used, we have noted that a door about 18 by 30 inches is provided in the rear wall behind the furnace, and *often left open!* The great inrush of air may be imagined. Upon inquiry as to why this was done the reply was:—"The furnace gets so hot that it melts the brickwork, so this air cools it!"

327. With a furnace so arranged practically all of the heat must be transmitted to the boiler by conduction and convection which is not conducive to efficiency. See Sect. 175. Consequently the flue gas temperature will be very high unless reduced by admission of excessive air as above noted. The gases will short circuit through the wide center space between the tubes. There is a bad soot lock and ash pocket at the bottom of the two middle passes, so that often holes are left in the arches for such material to fall through into the furnace. This also short-circuits the gas. In the overhanging portion of the drum the water will be stagnant which often causes pitting. Other deficiencies could be listed but the above are sufficient to show that this design has nothing to recommend it except low first cost, but a more expensive one to operate would be difficult to conceive.

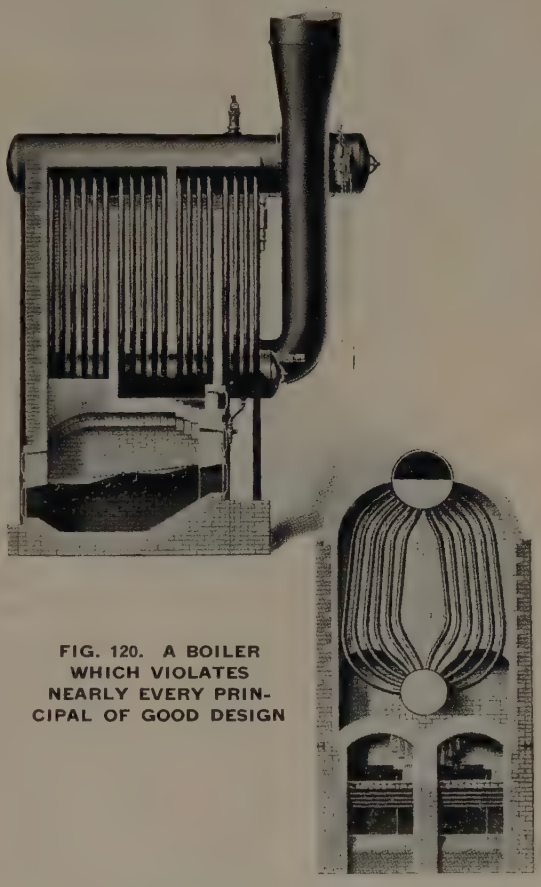


FIG. 120. A BOILER WHICH VIOLATES NEARLY EVERY PRINCIPAL OF GOOD DESIGN

328. A variation of the preceding scheme is to place the drums parallel to the boiler front, put a Dutch oven in front, and a row of tiles behind the first and second tube banks so that the gases ascend the front bank, descend along the second bank, and ascend again in the third bank, then pass out. Sundry makers offer such arrangement, and Fig. 121 shows one containing an additional feature as to the method of feeding. The feed enters the bottom drum at the rear which is fitted with a separate apartment into which the two rear rows of tubes are connected. The water passes up these rows and into the top drum, thus enters the main circuit.

329. While at first sight this arrangement looks reasonable, an analysis of it suggests the possibility of grave danger. Experiment:—Fill a thin glass tumbler with hot water and place it on a marble slab or iron block. At once it cracks and the bottom drops out. Why? Because the sudden cooling and contraction of the bottom causes such a stress in the joint between the bottom and the cylindrical part that it tears loose. *There is always a severe stress in every plane on each side of which very different temperatures exist.* In consequence of this it seems reasonable to suppose that as there is such a difference of temperature between the water inside the feed compartment and that in the drum, there must exist a severe stress along the two lines in the drum plate where such temperature differences exist. This is a menace of safety.

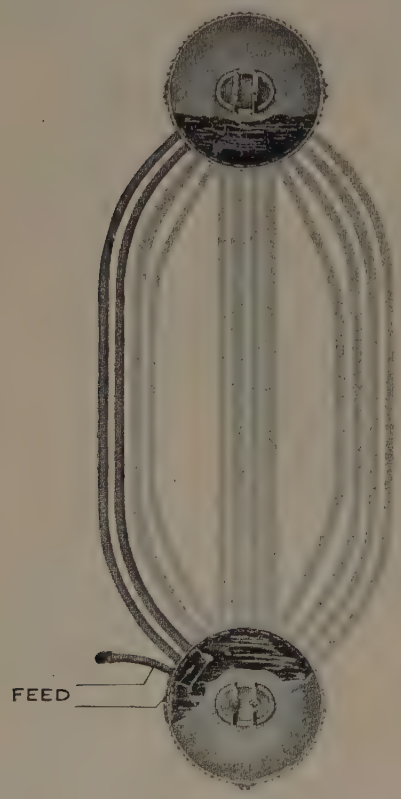


FIG. 121. BOILER WITH FEED COMPARTMENT IN MUD DRUM

330. Other than this feature there is nothing about the arrangement which requires extended analysis. Even if the top drum be made very large in proportion to the rating of the boiler, the water endurance surface will be relatively small. The circulation of water in the second tube bank is uncertain, and if it descends the action is contrary to Sect. 132. The objection of vertical steam generating tubes and the liability of their distortion as pointed out in Sect. 287 with reference to Fig. 99 also exist here. For the same reason this design will prime excessively if there is a sudden fluctuation of steam pressure, and *all* the tubes will be subject to the "pop-bottle" action described in Sects. 84 to 96, and Figs. 43 and 44. To such a degree is this true that one maker of this general type arranges the top drum as shown in Fig. 122 in which partitions are so placed as to provide at each end of the drum a compartment to receive the water which is ejected into the steam space when upheaval takes place. These spaces are drained by traps, a plan not favored by good engineers. The assumption is that the water will drop into these compartments, while steam alone passes to the collecting pipe. This does not prove out, however, as the steam becomes so emulsified with water that it inevitably is very wet, and the consequences of this are shown in Sects. 84 to 87.

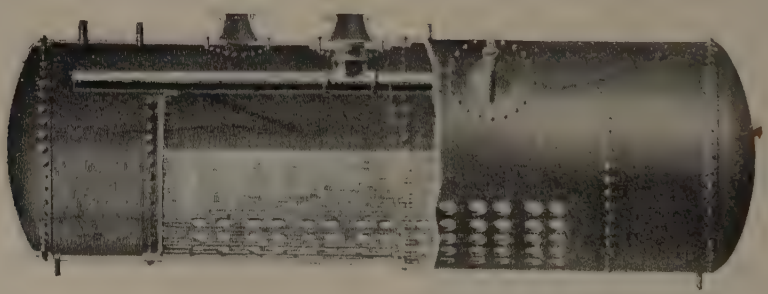


FIG. 122. DRUM WITH WATER-CATCHING SPACES AT EACH END

331. Similar scrutiny of other abbreviated designs will reveal that apart from first cost they have no real advantage, and that he who buys them is "saving at the spigot and losing at the bung." See Sects. 334 to 338.

Supplement to This Chapter.

332. After the above was written inquiries from widely distant parts of the world proved the necessity for some additions to the above discussion, hence it was decided to insert here the information necessary to answer the most important of such inquiries.

333. A Design Based on Rankine's Law. Fig. 123 is a diagram of the water circuit of a design which has the merit of being original, at least. The designer set out to produce a strict counter-current action between the gases and the boiler water. The flow of water and steam is indicated by the arrows inside of the tubes and the course of the gas is evident. This design was worked out to conform to Rankine's law as it originally was worded, and as stated in Sect. 129.

The result is the Belleville coil boiler with direction of the water flow reversed, that is, from the drum downward through the coil to the furnace, then upward through a short up-comer. To compel such flow a check valve has to be inserted into the coil near the drum. This closes when a sudden evolution of steam tends to drive the water upward. A second check or "anti-priming" valve, to prevent "pop-bottle" action, is inserted where the water passes under the horizontal baffle in the drum.

All the heat imparted to the coil has to pass through the part directly over the fire! If the boiler operates up to such capacity that the tube surface is *not covered by water*, other than momentarily, the tube will burn per Sect. 31.

It is claimed that this design cracks from the tube surface any scale which may form and sweeps it into the drum above. While such action is not complete, because we have seen bottom tubes heavily scaled and burned, considerable action of this kind does occur. It is due to rapid expansion and contraction of the tube as steam or water alternately sweeps along, but such action must cause fatigue of the metal.

The expected superiority of this design was based on the counter-flow of water and gas causing the upper tubes to produce an economizer effect wanting in other designs, but no information available shows a fuel efficiency greater than obtainable from several other types. On the other hand, the rate of working at which the tubes are liable to burn is quite below that now necessary in plants showing highest efficiency of Capital, which takes precedence of all others.

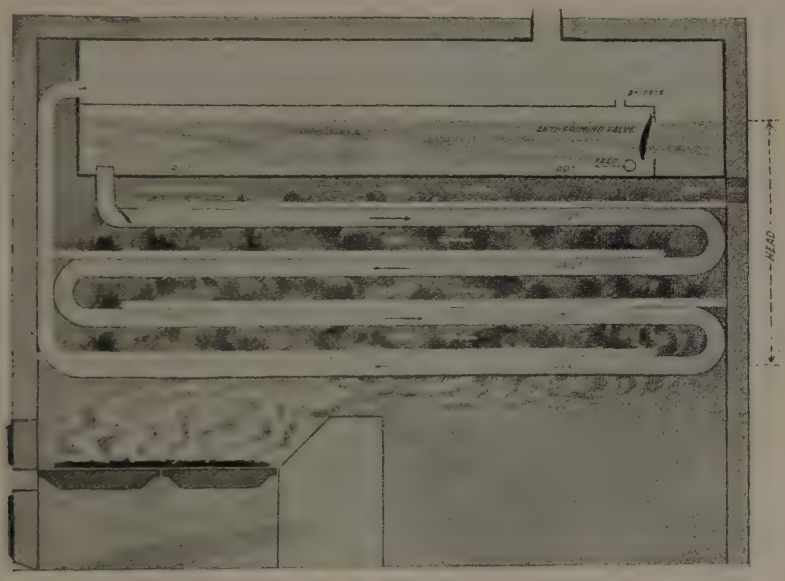


FIG. 123. WATER CIRCUIT OF BOILER CONFORMING TO RANKINE'S LAW AS STATED IN SECT. 129

Check valves in the water circuit so frequently cause trouble that they are not now sanctioned by experienced operating engineers.

This design is ingenious. It shows a deeper understanding of underlying principles than usual among those who have undertaken a similar task. Its deficiency is that there is *no circulation* as that term is usually understood, but a forced travel of water and steam which thus far appears to have developed no advantage suf-

ficient to offset the obvious disadvantage that to operate without danger of burning tubes this design would require for its lower tubes a material unaffected by high temperatures, and such is yet to be discovered.

334. Revival of Deficient and Obsolete Designs. There is no better proof of the statements of Messrs. Azbe, Lucke, Bertin and others herein quoted than the frequency with which boilers long ago proved to be deficient and therefore discarded, are regularly revived, vigorously advertised, boldly proclaimed as great improvements, and purchased by many, usually because

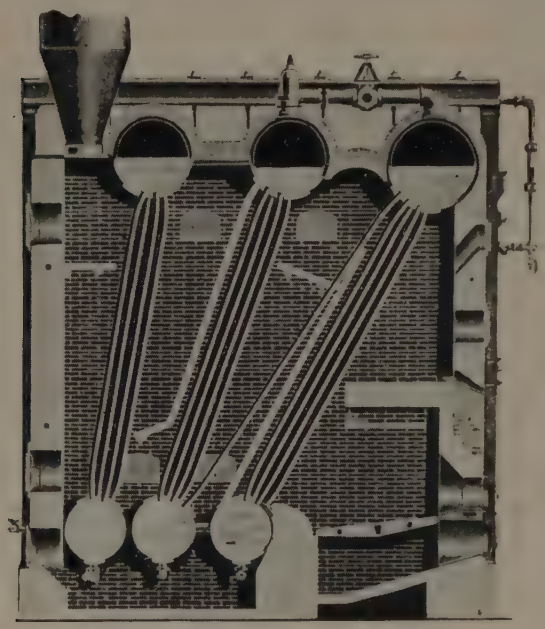


FIG. 124. AN OBSOLETE DESIGN

of low price, but *more often because such buyers are unable to distinguish between a good and a poor boiler design.* A few illustrations will be profitable.

335. Fig. 124 shows a design used in the United States 30 years ago, principally in Steel Works, but which now appears to be obsolete. The front and middle top drums were connected by a saddle pipe, the front and middle mud drums by one row of horizontal nipples, and the middle and rear top drums by a similar row of nipples. No tubes connected the front and middle top drums.

From Sects. 296 to 299, and Figs. 103 to 105, it is evident that water will pile up high in the front top drum, hence the gauge glass will fluctuate badly and water be pulled through the saddle pipe and into the steam main. The suction on the nipple connecting the mud drums will pull the water out of the top middle drum. The tube connecting the top front drum to the middle mud drum is so inadequate that in sundry cases users found it imperative to connect these mud drums at the bottom by an 8-inch pipe extending under the drums precisely as the saddle pipe extends across the drums above. Even with such change this arrangement was so unequal to the task of operating at high ratings and of delivering even fairly dry steam with reasonably steady water level, that it gradually fell out of the race, hence further listing of its obvious deficiencies is unnecessary.

Yet periodically this faulty general scheme is revived in as many shapes as there were colors in Joseph's coat. Note that Fig. 101 is only a typical variant of it.

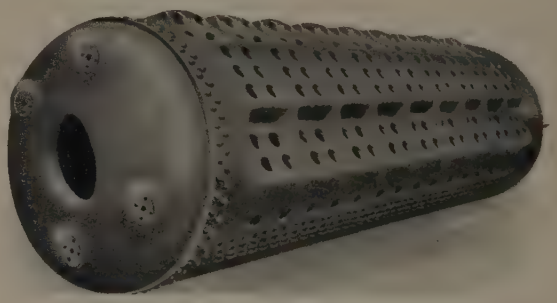


FIG. 126. SHOWING PRESSED TUBE SHEET

336. An Example from Europe. Fig. 125 is a typical illustration. As usual in such cases, its makers start out with extraordinary statements in which consistency and accuracy are conspicuous by their absence. They claim that this "water tube boiler is the very embodiment of simplicity, *being the straight tube type, and this at once makes it far superior to any bent tube type water tube boiler.* The bent tube type of water tube boiler does not come under the category of simple design, and in consequence is falling into disuse." In view of the fact that the use of curved tube boilers is increasing far more rapidly than any other (Sect. 155) and that their superiority has been proved so often in this book that reiteration of the fact is superfluous, it is pertinent to note that the fiction in the above quotation permeates even the description of the boiler which it so extravagantly extols. Scrutiny of Fig. 125 shows 28 tubes per section, of which exactly 25% are of the disparaged bent shape, two of which contain short reverse curves of a kind not used by other standard designs shown

in this book. The reader must decide for himself whether to attach much weight to statements of anyone whose description of a simple matter like this is subject to 25% of error.

337. Fig. 126 shows the drum construction, in which the tube seats are stamped flat in the cylindrical part. Exact mathematical determination of the factor of safety is impossible with such form of parts. See Sect. 548. Regarding the alleged superiority of having a group of front and middle mud drum will produce the same trouble as occurred with Fig. 124; the boiler will prime severely for the identical reason given in Sects. 304 to 312, which is evidenced by the additional drum over the steam outlet; and finally, this design has 7 drums as compared with only 4 in Fig. 102, and many others, including the Kidwell Ring-Flow boiler. This is directly contrary to the maker's claim of being "the very embodiment of simplicity."

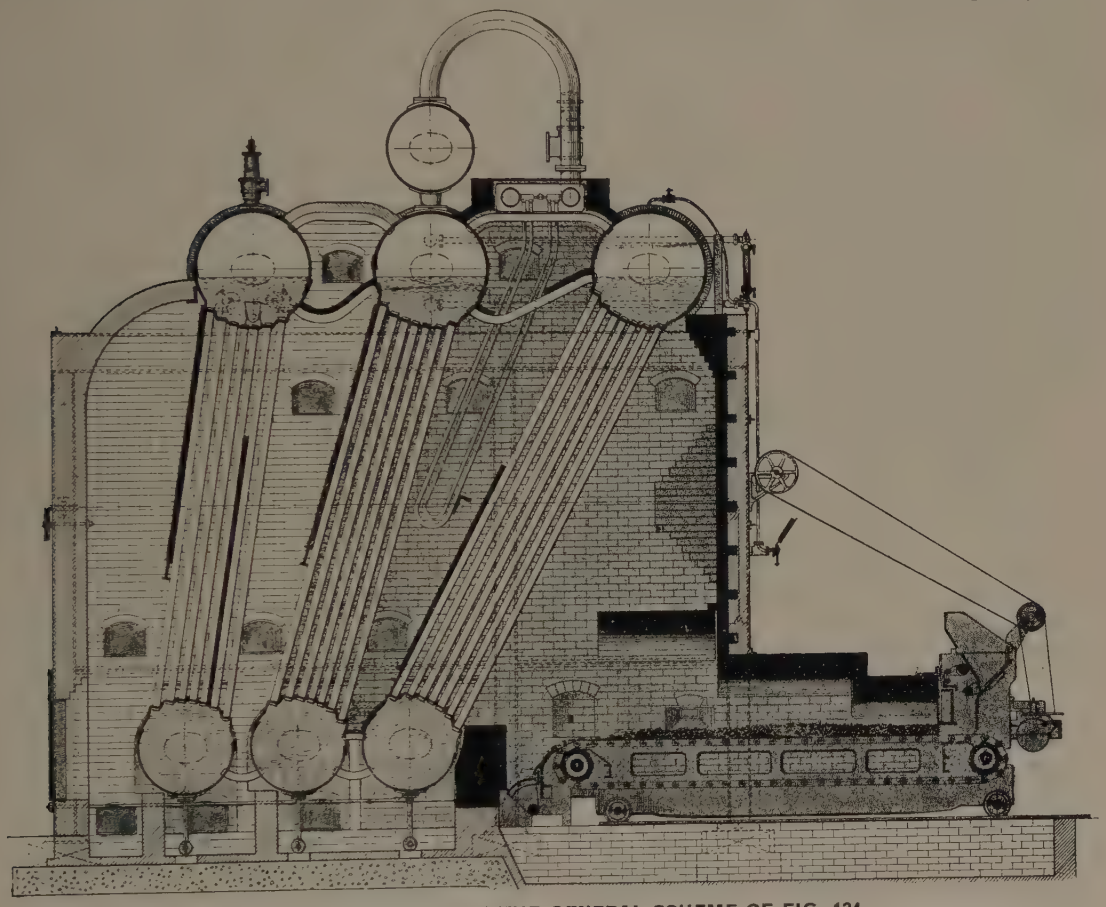


FIG. 125. A REVIVAL OF THE GENERAL SCHEME OF FIG. 124

straight tubes between two such tube sheets, see Sects. 152 to 155, 243 and 244.

Comparison of Fig. 125 with Figs. 103 to 105 and 124 will show that in the first the water line will be similar to that in Fig. 105; the rear top drum will lose part or all of its water and be subject to the same liability of overheating as pointed out in Sect. 298(b); the water will fluctuate in the glass with every change of load; the actual water endurance surface will be only a fraction of the apparent surface as shown in the cut; the throttled water passage between

The proportioning of the water circuit is extremely faulty, as shown by Sect. 52. A flow diagram, Fig. 33, will show that immediately.

The superheater as shown has no facilities for drainage, which is particularly objectionable when connected to a boiler delivering wet steam. If the water is dirty or forms a scum on the surface, the results are far worse; see Sect. 534.

338. Fig. 127 shows a variation of this design containing a "preheater," the objections to which are explained in Sects. 201, 202, 213, 219, and 222 to 224.

In consequence, this resurrecting of an obsolete design has not produced anything ranking as an improvement. Unconsciously the makers show that when they say with emphasis, as representing a remarkable performance, that with this "boiler *overloads of 75%* have been carried for months." To check this with present requirements compare Sects. 25(b), 183 to 186, and 486 to 499.

appears that these sections merely duplicate Fig. 92 on a small scale, and the deficiency of this general scheme is shown in Sects. 281 to 291.

Four nipples or rows of nipples, connect each pair of upper front drums, and three connect each pair of rear top drums. The bottom drums are connected by one nipple or one row of nip-

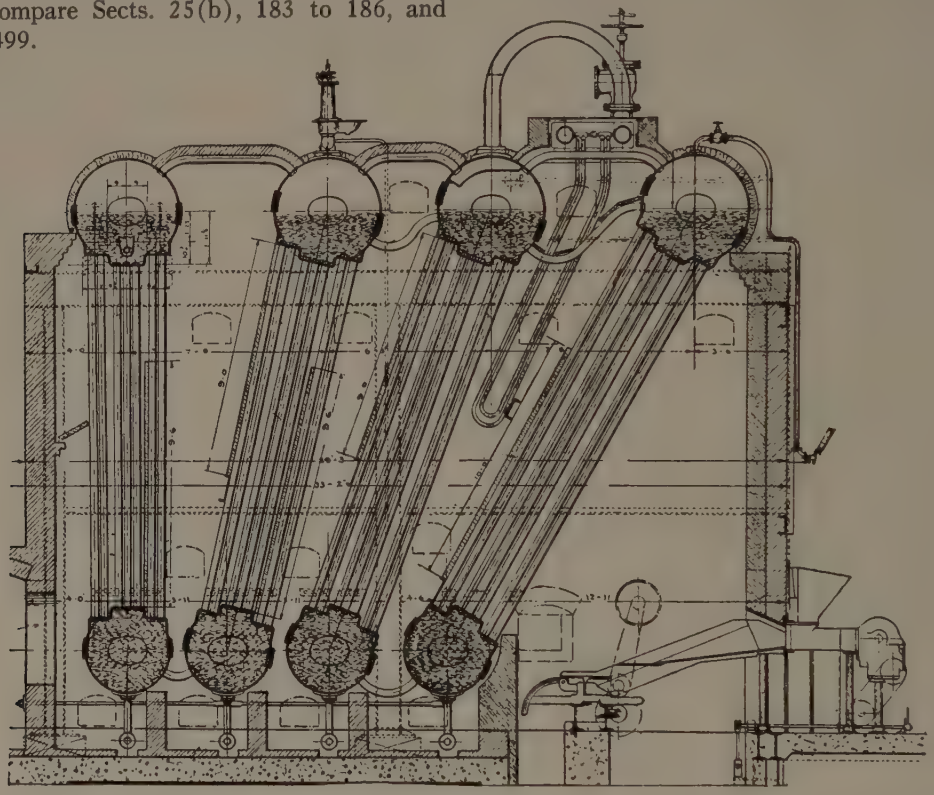


FIG. 127. "PREHEATER" BOILER

339. Another European Design. No student of boiler development can fail to note how the continental European mind runs to complication. See Figs. 71 to 73, 80, 81, 84, 87, 88 and 89. This is more remarkable because of the extent to which such engineers have developed technical research in matters pertaining to steam.

British and American engineers generally shun complication to the same degree, yet occasionally both of these produce designs which are far from simple. Fig. 128 shows one which originated in England but is now also made in the United States. It is unique in many ways and the scheme is well carried out. It is a species of sectional boiler in that it is made up principally of elements each consisting of 21 straight tubes terminating in small drums whose axes are parallel to the tubes. But upon scrutiny it

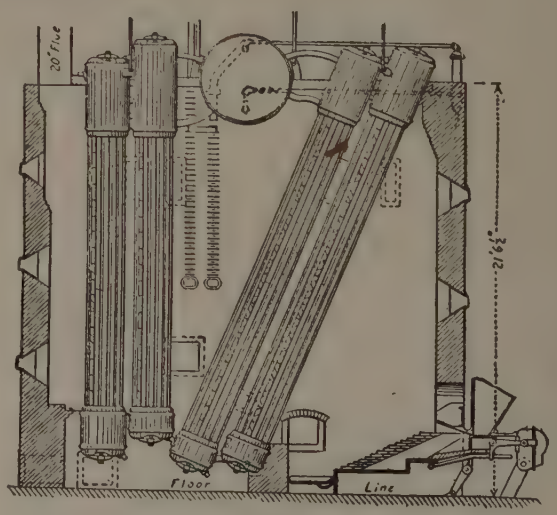


FIG. 128. AN ENGLISH DESIGN

ples. The 4 sets of tubes and drums form an independent section, and similar sections are set side by side to make up the necessary amount of heating surface and width, but the sections have no connection with each other, apart from the tubes uniting the inner top drums with the horizontal cross drum which serves as a general steam and water container.

The small drum diameter enables this design to be built easily for high pressures. As an offset to this, the greater the number of drums, the greater the number of joints, which is objectionable. Note Hutton's statement in Sect. 547.

The manufacturers of this boiler claim for it "unrestricted circulation, very dry steam, and large overload capacity" beside other advantages. How one could claim unrestricted circu-

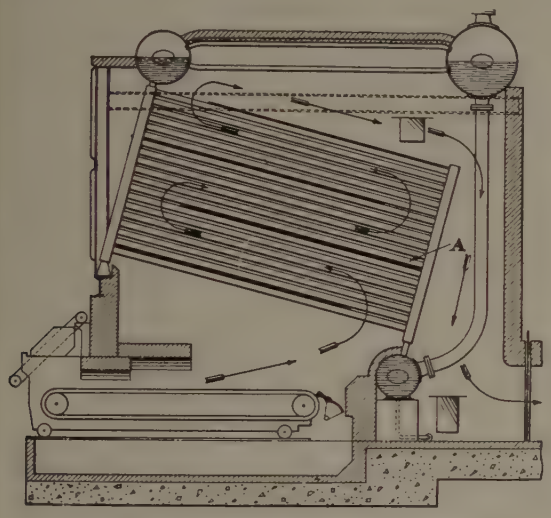


FIG. 129. EUROPEAN HEADER DESIGN

lation is difficult to see; the statement is made that "the feed water enters the top rear unit drums and passes down in the rear tubes and up the tubes in the front units." It must therefore pass through the nipples between the bottom drums, and after ascending the front units it must pass through the short tubes to the horizontal drum, then through similar tubes to the rear top drums again. Therefore the restriction at these points will be as great as in header and nipple types, and often greater than in such types not many tubes high. A flow diagram as per Sects. 72 to 76 and Figs. 33 and 34 will show how this arrangement falls far short of the essential requirement in Sect. 52, hence the claim of unrestricted circulation for this design cannot be sustained.

For reasons given in Sects. 304 to 312 this design primes; also, the higher the rating being developed the more the water builds up in the upper front drums until it fills them, so that both steam and water pass at high velocity through the top over-comer tubes into the horizontal drum, precisely as it does through tubes F in Fig. 105.

Therefore this design is subject to all troubles arising from widely different and fluctuating water levels in the various drums.

340. The makers also claim that:—"The counter-current flow, or the coldest water meeting the coldest gases, produces the maximum economy in the transmission of heat. This feature has been perfected in *no other boiler* so thoroughly as in" the one under discussion. According to the scheme of baffling shown in the maker's catalog the gases flow directly from

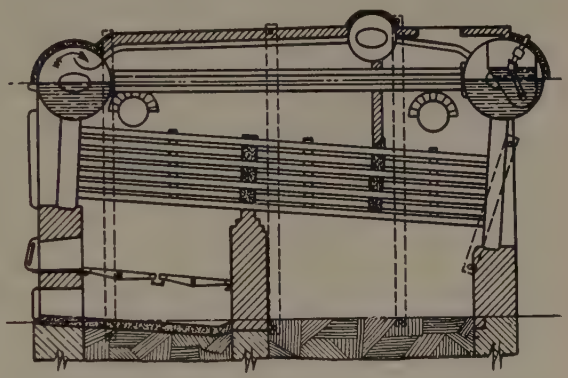


FIG.130. AN AMERICAN DESIGN OF TWO DECADES AGO

front to rear, approximately horizontally, hence *approximately at right* angles to the tubes, hence in the rear bank there is not a true counter-current flow of water and gas as required by Sect. 132. Assuming that such counter flow actually existed, it would even then be untrue that this feature is not so thoroughly secured in *any other boiler,* since reference to Sect. 461 will show that in the Kidwell boiler the counter flow action is actually *secured to the letter!*

341. An European Header Design. We shall discuss Fig. 129 at the request of an European correspondent. This is only one variant of a general scheme which is constantly being revived in some form which is abandoned after being tried out in service. We shall therefore point out why the general scheme is faulty, by discussing several typical examples of it.

Fig. 130 shows one which was brought out about 20 years ago by an old and well known

concern, advertised extensively, pushed vigorously, sold at prices lower than usually asked by competing designs, and installed in numerous plants. Yet it has been obsolete for years.

A brief analysis will show why this was inevitable. Besides those deficiencies inherent to all header boilers as disclosed by Sects. 68 to 77 and 229 to 280, this design introduces some others which intensify its shortcomings. Figs. 9 to 12 prove that a considerable head of water is necessary for producing a flow from the front to the rear drum, and the smaller the water passages the greater this head must be.

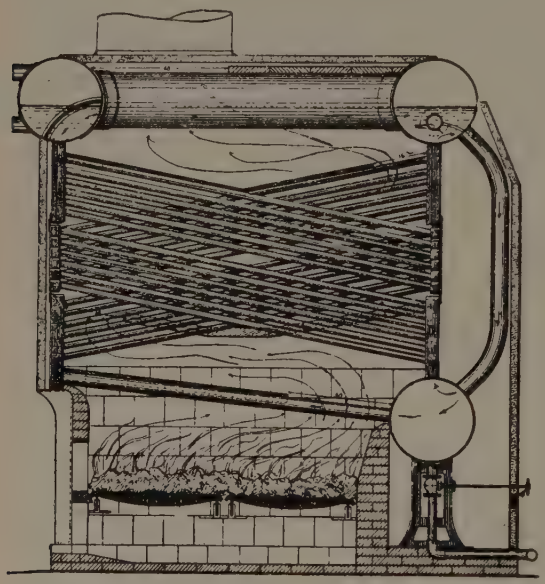


FIG. 131. DESIGN TESTED BY U. S. NAVAL BOARD

Yet Fig. 130 is based on the obviously impossible hypothesis that the water in both drums *stands at the same level.* Fig. 10 shows the actual condition in the front drum, and the higher the rating at which the boiler is working the more vigorously the water will spout up into the drum. That this happens is evidenced by the baffle shown in front of the over-comer tubes. That this device is ineffective is apparent from Sects. 296 to 299 and Figs. 103 to 105. Therefore the front drum will fill with water which will flow into the over-comer tubes, flood the small outlet drum, deposit mud into it (see Sect. 534) and finally pass over into the steam main, duplicating the action described in Sect. 351 with reference to Fig. 140, the top arrangement of which is identical with that in Fig. 130.

Precisely as in Fig. 105, the water in the rear drum of this design will drop lower and lower as the boiler output is increased, and finally it will disappear from this drum. The consequences will be as stated in Sects. 297 to 302 and this explains the presence of the pan under the feed pipe terminus.

These boilers were not suspended from overhead beams, as long ago proved necessary for good results. The headers rested in troughs supported from below, hence there was insufficient provision for free expansion, therefore the brick setting usually cracked badly soon after the boiler was started and firing began.

In consequence, this design failed to survive.

342. In 1901 U. S. Navy engineers made 17 tests on the boiler shown in Fig. 131 when fired

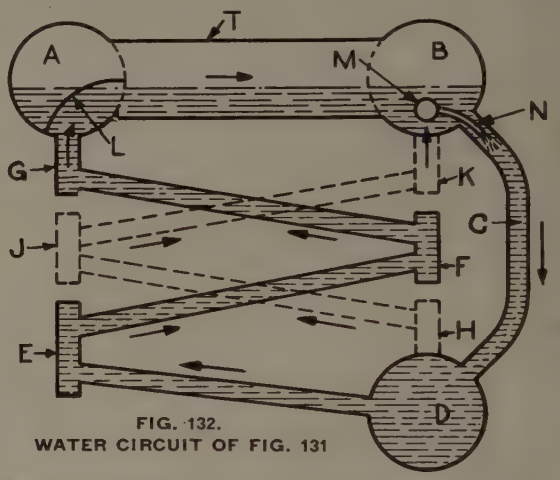


FIG. 132.
WATER CIRCUIT OF FIG. 131

with coal, and 14 tests when fired with oil. Particulars are given in *Report of The "Hohenstein Boiler"* and *"Liquid Fuel" Boards,* Washington, 1902. Fig. 132 shows the water circuit which is divided into two paths; one goes from the mud drum through headers, E, F, and G to drum A; the other through headers H, J, and K to drum B. Feed enters at M and is projected into the down-comers C through small nozzles N.

The furnace was 7 ft. 11 in. wide; heating surface averaged 2152 sq. ft.; drums A, B, and C were 24-in. dia.; there were 4 connecting drums T each 16 in. dia.; 15 down-comer tubes C each 5 in. dia.; 16 tubes over the fire, each 4 in. dia. and 7 ft. long; and 384 upper tubes 2 in. dia. and 9 ft. long.

The 17 tests when coal was burned gave the following results:—gauge pressure, 264 to 274 lbs.; water evaporated per sq. ft. of heating surface 4.33 to 9.64 lbs. during 13 tests and 10.25 to 14.15 lbs. during 4 tests; maximum heat absorption by boiler 73.4% when evaporating

4.38 lbs. water from and at 212° per sq. ft.; minimum heat absorption, 59.4%, when evaporating 12.54 and 14.15 lbs. from and at 212° per sq. ft.; average heat absorption of all tests 66.13%; moisture in steam 1% to 3.2%, average 1.76%; coal, high grade containing 14,067 to 14,992 B.T.U. per lb. as fired.

In the oil-fired tests the pressure was 272 to 277 lbs., maximum heat absorption 71.5% when evaporating 5.18 lbs. per sq. ft.; minimum heat absorption 53.4% when evaporating 16.7 lbs. per sq. ft.; average heat absorption 65.9%; average moisture in steam 1.06%.

Note that the heat absorption above mentioned gives the *efficiency of boiler only, not the combined efficiency of boiler and grate* which figured out 1% to 5% lower than the efficiencies above given. These results are low and would not today be tolerated in any well operated plant in the United States.

Note carefully that in Fig. 131 the water circuit is such that approximately only *one-half* of the total water flowing is delivered into the top front drum; yet to prevent spouting like in Fig. 10 it was necessary to provide the baffle L so arranged as to direct the water far into the connecting drums. And to prevent water filling the front drum these connecting drums T were made 16-in. in diameter! The ratio of area through the drums T to the row of tubes over the fire is 4.6 and if the upper drums be half full of water the ratio of water passage areas will be 2.3.

Yet with such proportions it was found that with 2 to 3 inches of water visible in the glass the steam showed a maximum of 3.2% of moisture, hence in later tests the water was carried lower, and often *with none showing in the glass!* Yet even under this extreme condition, and with small specific volume of the steam due to the high pressure, the percentage of moisture in the steam was high, though better when oil was burned, because the fires could be kept more steady than when firing coal by hand.

Though testing experts could venture to operate with no water visible in the glass, such a condition could not be tolerated in any plant in regular commercial service; the water would have to be carried at a reasonable height in the glass with a consequent serious increase in the amount of priming.

The Navy Board therefore recommended that the diameter of drum A be increased to 42 inches, but nothing further appears to have been done to develop or exploit this design.

343. From the above it will quickly appear that the design in Fig. 129 is inferior to those in Figs. 130 and 131.

In Fig. 130 eliminate the upper of the two rows of straight tubes connecting the two drums; reduce the diameter of the front drum by about one-third; then omit the baffle in front of the over-comer tubes, also omit the outlet drum connected to these tubes; connect the front drum to a header below with nipples which greatly restrict the circulation; discard both the mud pan in the rear drum, and the connections between this drum and the header below it; and add rear down-comer tubes like C in Fig. 132; then the result will be identical with Fig. 129.

That the front drum is totally inadequate as to diameter is proved by the results from Fig. 131 and the Navy Board's recommendation as to increase of this dimension. In comparison with Fig. 131 the area of water passages between the two drums in Fig. 129 is woefully inadequate, yet in Fig. 131, with only about *one-half* of the water passing through drums T, the baffle L was necessary, and even it could not prevent excessive priming unless the water was carried at or near the bottom of the glass. Accordingly, Fig. 129 is still more deficient in these particulars, and will prime excessively.

The nipples between header and front drum will aggravate the priming by spouting like Fig. 10 and the throttled water path there will cause steam locking of tubes, with consequences as in Sects. 249 to 255. Therefore, Fig. 129 cannot develop with safety ratings greater than 50% of those possible from Fig. 131.

The rear drum is liable to lose its water as in Fig. 105, with identical consequences. No information is given, in any cut we have seen, as to where the feed enters. If it enters the rear top drum a mud pan will be necessary as in Figs. 111 and 130 to prevent uncovering the end of the feed pipe, and if the water line gets low the feed spilling over the edge of the pan may strike a hot sheet and crack it, as in Sect. 321.

The over-comer tubes will spray a mixture of steam and water violently into the rear drum, as shown in Figs. 76 and 105. This also will cause the steam to be very wet, which trouble will be aggravated if the feed is foamy, or forms scum on the water surface.

A soot lock at A is inevitable, and means to prevent it or to remove the soot from this corner are not in evidence. This is a deficiency not tolerated in modern plants.

Finally, official tests of Fig. 131 developed fuel efficiencies which under the most liberal interpretation cannot be classed as satisfactory in comparison with those obtainable from boilers now on the market, yet from the above it follows that Fig. 129 could not produce results which are better, if it could do as well.

A more minute analysis of this design, and checking of it item by item per Sects. 381 to 386 will reveal other deficiencies, but the above shows that this design and all others of its general kind contain inherent shortcomings which exclude them from any list of boilers capable of meeting the requirements of steam plants operated along the lines now known to be essential for producing the greatest return on the investment, or as to efficiency of Capital.

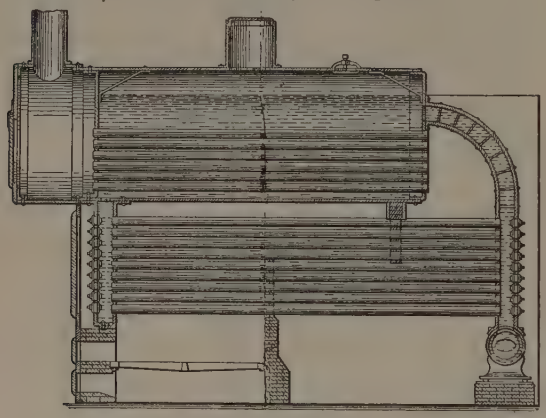


FIG. 133. A HYBRID DESIGN

344. Hybrid Designs. Many good mechanics who unfortunately lack the technical knowledge required by a boiler designer have attempted to produce a combination of fire tube and water tube boiler. No such design we have seen has made good. Fig. 133 shows a typical attempt. Since the tubes over the fire are horizontal there will be no definite direction of water flow, and this design is merely a variant of Fig. 14 with nothing ranking as an improvement, hence will pass into oblivion along with its predecessor.

It will be found that the cost of such hybrid designs usually equals or exceeds that of a good water tube boiler possessing many points of superiority, which fact explains why such designs are usually either stillborn or die of inanition.

345. Sectional Construction. In times gone by boiler design, like domestic architecture, ran through various "styles" or schemes of development strongly in vogue until their deficiency was proved, then they were quickly abandoned. One illustration will suffice. From 25 to 40 years ago "sectional" construction held the stage to a degree which seems ludicrous to engineers of today. It was carried to extremes which resulted in excessively throttled circulation, small steam and water volume, even smaller water endurance

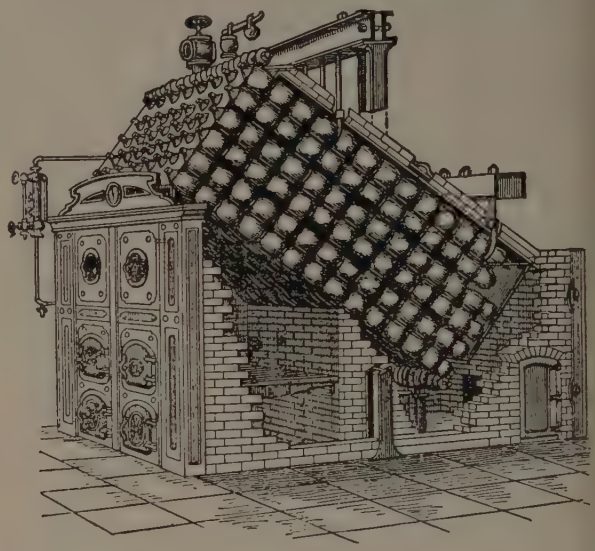


FIG. 134. SECTIONAL BOILER

surface, excessively wet steam, and many fatal accidents. The latter caused a final change of opinion, and the general scheme long ago fell into disfavor.

Figs. 18 to 30 and others show examples of such construction. But Fig. 134 shows the idea

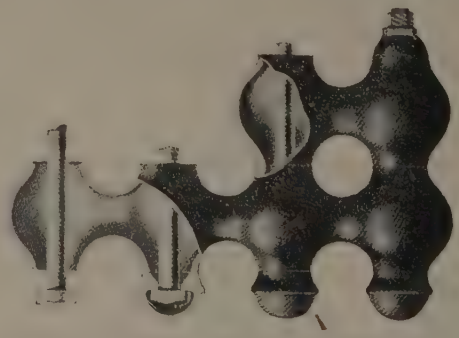


FIG. 135A. SHOWING DETAIL OF CONSTRUCTION

carried to an extreme. This boiler was built of malleable iron elements consisting of spheres united by necks, and milled to a close joint on top and bottom. These sections were strung on vertical steel bars with screw caps at top and bottom, by which the whole assemblage could be drawn up tight. Fig. 135A shows details.

The unequal expansion of the bars surrounded by water and the elements exposed to hot gas caused trouble. The bars would stretch, and leaks would result. There were no means of cleaning the elements. Steam space and water endurance surface were too small, so the steam was very wet. The general design was mechanically clever, but it did not survive.

boilers. This design attempts to reduce the amount of priming inevitable in Fig. 102, and the drum 8 is inserted as a separator in the path of the steam from 7 through tubes 12 and 13 to outlet 32. This designer, like most of his predecessors, *assumes* that the water in drums 5 and 7 will stand at the same level, *so he attaches his water column connections to drum 5*. Reference

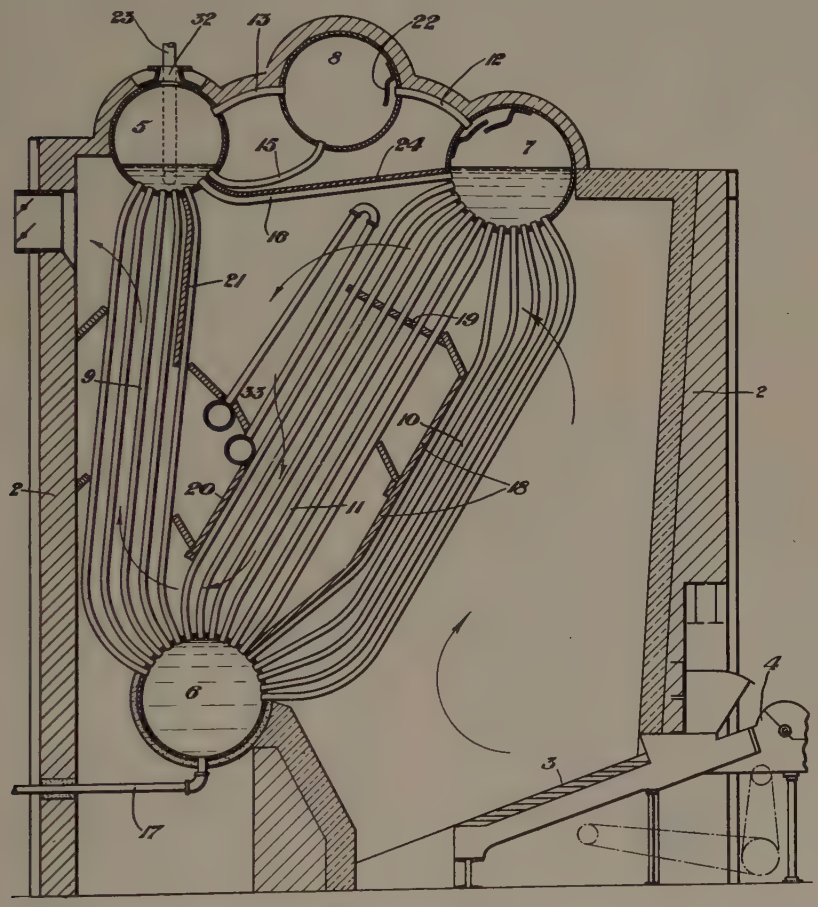


FIG. 135B. ANOTHER DESIGN WHICH PRODUCES WIDELY FLUCTUATING WATER LEVELS AS IN FIG. 105

Today some makers still urge sectional construction as an advantage, but the lessons drawn from two or three decades of actual operation prove otherwise. The reason is clearly expressed by Hutton in Sect. 547.

We cannot close this chapter better than by presenting Fig. 135B from U. S. Patent No. 1,432,721, subject, "Boiler," issued Oct. 17, 1922, because this eloquently proves how little the average boiler designer knows, or even suspects about the wide variation of water levels in

to Sects. 296 to 298 and Fig. 105 will show that as soon as Fig. 135B begins to steam the water will leave drum 5, and the harder the boiler is steaming the lower the water in tube bank 9 will be! Therefore, *as designed this boiler when operating can show no water in the gauge glass!* But if the gauge glass connections are transferred to drum 7 the result will duplicate what occurred with the arrangement in Fig. 102!

As this feature alone condemns the design further comment seems superfluous.

Throughout this chapter and particularly in Sect. 236 we have shown how boilers of the general design of Fig. 68 prime violently and carry out mud with the steam.

Fig. 135C from a U. S. Patent Office specification recognizes this deficiency and attempts to overcome it by imposing on a header design the scheme shown in Fig. 135B, the main object of which is also to reduce the intensity of priming.

It is evident that in order for a boiler like Fig. 135C to operate, the water in drum 7 must stand at as great a height above that in drum 5 as has been found to exist in Fig. 105. In consequence, drum 7 must fill to such extent that water will be pulled over with the steam through tube 12. This result is unavoidable and it largely defeats the purpose of the design since as in case of Fig. 122 it will be found that the emulsified water and steam will to only a slight extent separate when passing through drum 8.

If the water column is connected to drum 7 its indications will be fluctuating and irregular precisely for the same reason that an identical result occurs in Fig. 102. But if the column is connected to drum 5 it will show a false level

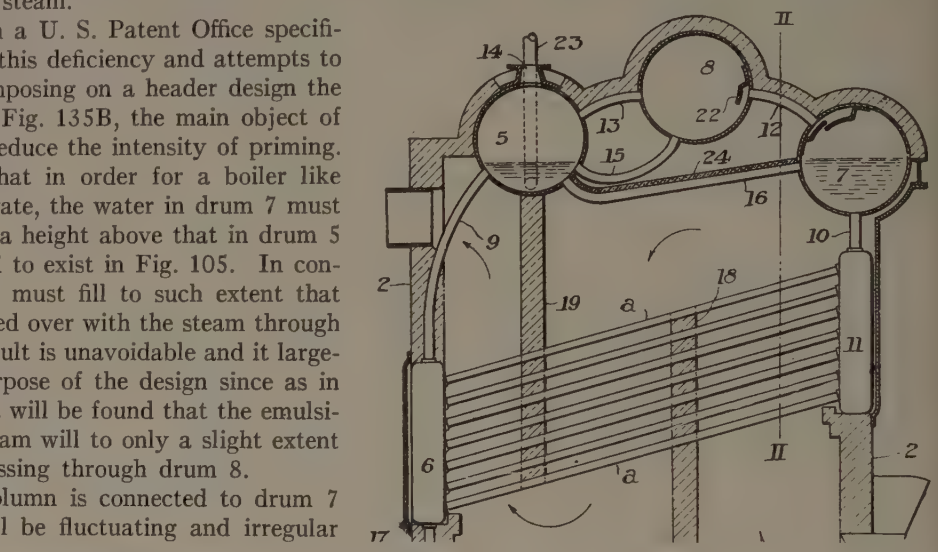


FIG. 135C

if low water occurs, because the water below the tube exit in drum 5 is trapped, *hence drum 7 could lose all its water without that fact being indicated by a gauge glass so connected!*

FIG. 135D

Supplement to Section 285

In that Section reference was made to the large drum heads required. Fig. 135D shows this more clearly than any description can do, and it also evidences the large number of stays necessary to support such sheets sufficiently.

It is obvious that with stays so closely placed it will be difficult for a man to work efficiently inside of such drum when he has to do cleaning, inspecting or repairing.

A Spark from the Furnace. No. 3

"After our experience with priming on our other boilers, we could not help but be very much impressed with the ability of the Kidwell Boiler to maintain a constant water level under the varying load conditions with which we have to contend. We have found that the Kidwell Boiler responds to forcing nicely and delivers superheated steam without the added installation of a superheater. Our experience with the Kidwell Boiler prompts us to say that we consider it the best boiler of its type on the market today."—S. H. Hunt, Chief Engineer, The Milwaukee Coke & Gas Company, Milwaukee, Wisconsin.

IV. Evolution of the Ring-Circuit Boiler

346. The ring-circuit or ring-flow principle, which is the *only one* that can produce correct circulation in the main water passage through a boiler, was discovered by Goldsworthy Gurney, an eminent Cornish engineer, and by him applied about the year 1826 to boilers used to drive steam carriages. He seems to have been the only one of the pioneer engineers who properly appreciated the necessity of *first ascertaining the laws of nature and then designing a boiler to conform to them,* and in engineering acumen he easily surpasses all of those who followed him. See the dedication of this book. "Mr. Gurney tried experiments to see how the water circulated in tubes. He took a glass tube bent in form of a hoop, Fig. 136, with a small hole near the top

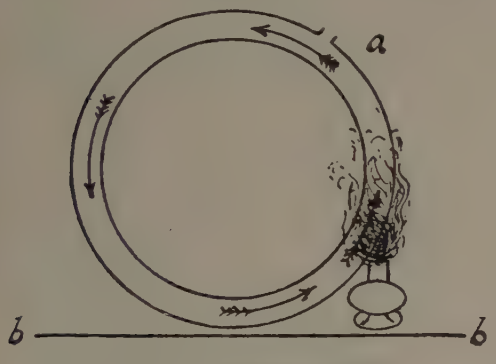


FIG. 136. GURNEY'S RING

for the escape of steam. To the water in the tube some light flocculent matter was added, and a spirit lamp applied at one side; the heated water ascended and colder water followed it up. The steam was allowed to flow off by the hole above mentioned, and the water descended in the other limb of the hoop. He found that a strong current was established in the direction of the arrows, which prevented any part of the tube from being left dry to the fire. Mr. Gurney's boilers contained many of the essential points of good modern water tube boilers, and he seems to have understood the principles of rapid circulation. *It seems strange that after such examples as those of Mr. Gurney, that the necessity of circulation was so obstinately overlooked in the later attempts with water tube boilers, numbers having been made EVEN IN RECENT YEARS in which no attempt seems to have been made to insure rapid and vigorous circulation, and the disasters which have occurred through tubes burning out might have been prevented by such experiments as those foreshadowed by Mr. Gurney with the glass tube.* Others have, however, within the last few years, experimented in the same direction, and have shown that with proper means for natural circulation, it is well-nigh impossible to drive water from the heated surface of the tubes."—Powles' *Steam Boilers,* pp. 85 and 87. This book was issued in 1905.

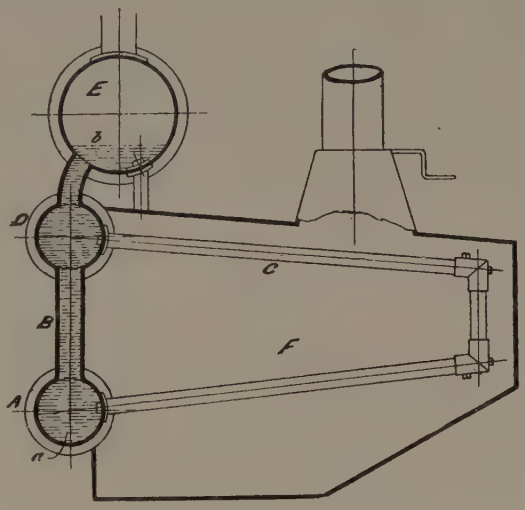


FIG. 137. GURNEY'S BOILER

347. This is a clear-cut proof of not only the necessity of circulation as shown throughout this book, but that the main principles underlying its action were discovered nearly a century ago. Unfortunately they were either ignored by or unknown to later designers, though a factor of no small influence was the mechanical impossibility of successfully building boilers in which such principles could be applied. Later, when such means were available, manufacturers naturally refused to scrap their former designs, even though deficient, so long as the public will buy them. "It is interesting, this waste incident to progress, this friction of the wheels of evolution. When St. Paul came preaching to a certain town, the idol makers of the place would have mobbed him, for 'their craft was in danger.' Lichten-

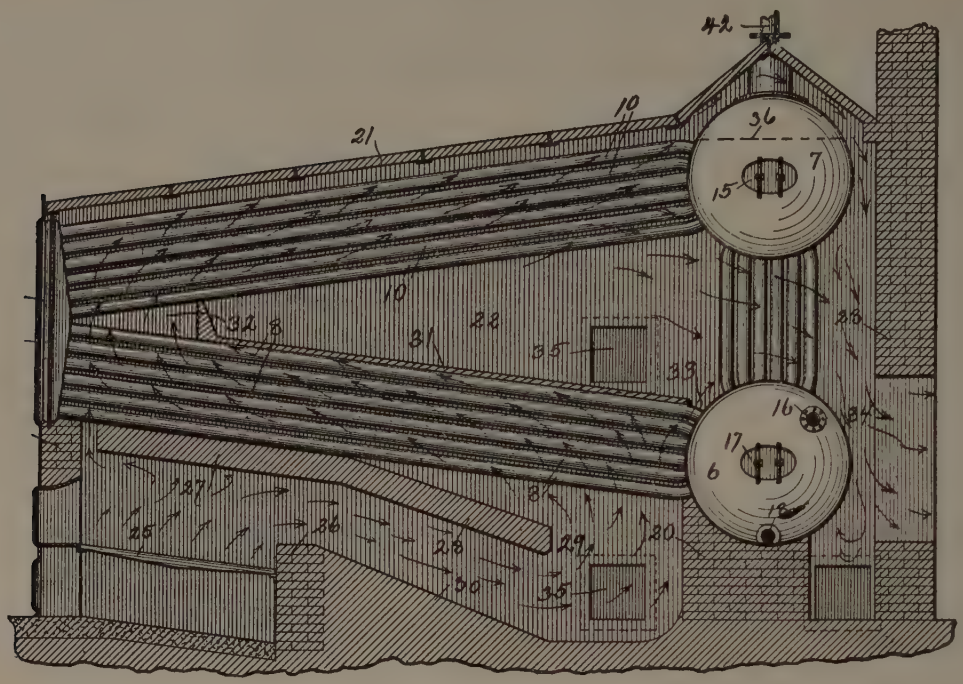


FIG. 138. DESIGN BY GEO. Y. BONUS WHICH GIVES ACCESS TO ALL TUBE ENDS

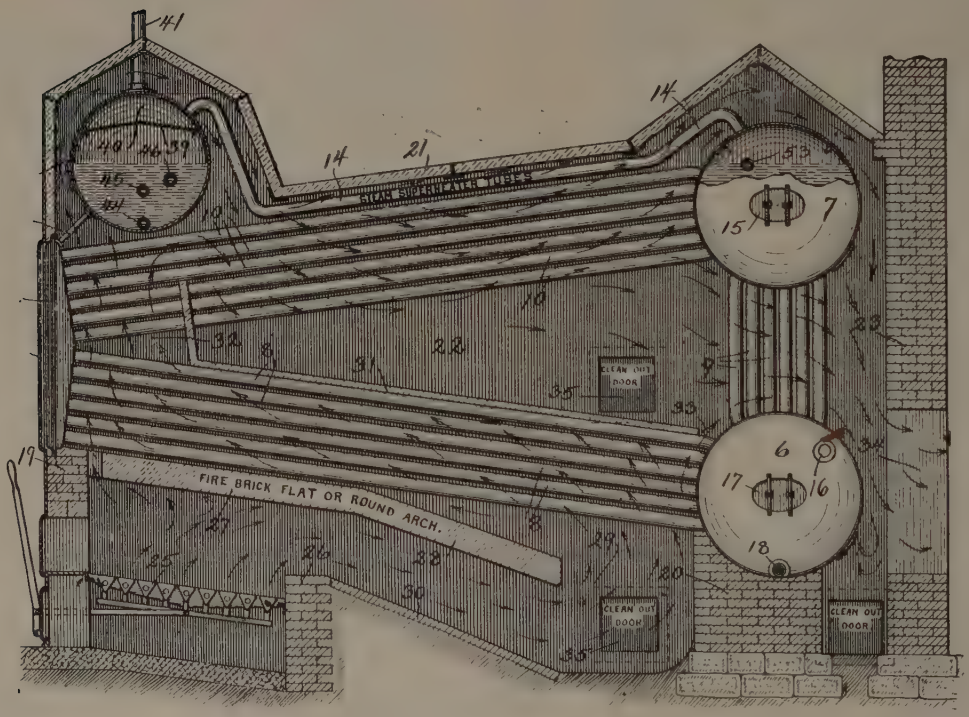


FIG. 139. DESIGN OF BONUS FOR INCREASING WATER ENDURANCE SURFACE AND DRYING THE STEAM

burg, in his Reflections, says: 'If mankind suddenly took to virtue, many thousands would inevitably be reduced to starvation.' "—Dr. Frank Crane, in *Friction of Progress*. The same spirit which actuated the idol makers influences every case in which antiquated machinery designs are threatened by improvements.

348. The case is exactly parallel to that of the steam turbine. Invented by Hero of Alexandria, it was the first form of engine known, and centuries later its principle was used by DeCaus and Branca, yet all this was forgotten for centuries until Parsons took it up and developed a successful machine operating on this principle. As in case of every such invention, this new form of prime mover encountered doubt and suspicion, but its merits overcame these, and its advantages for many purposes are now too well known to need further comment. The ring-circuit principle in boiler design has just as certainly demonstrated its superiority over all others, hence will be even more widely adopted, since unlike the steam turbine, *it has no competing design* which can produce equal results.

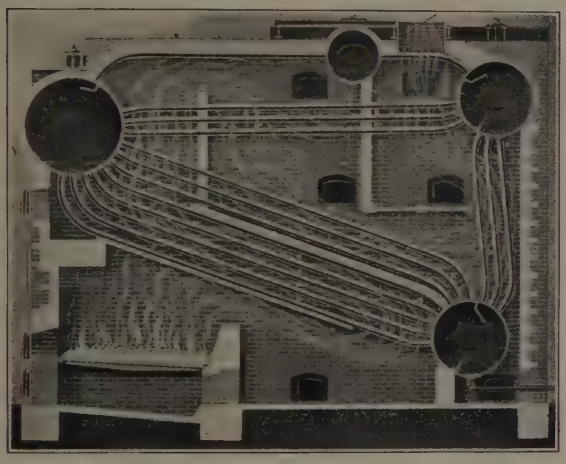


FIG. 140A. SHOWING WRONG PROPORTION OF WATER CIRCUIT

349. Fig. 136 is an exact reproduction of Mr. Gurney's original figure, the principle of which has been extensively copied, but as usual without credit to the originator. Fig. 137 shows one of his boilers, and the design is in numerous ways superior to many which are in high esteem today. His work was, however, forgotten for 80 years, and development proceeded along other and less correct lines as already shown.

350. Mr. Geo. Y. Bonus, of Chicago, took up the problem where Gurney stopped, and produced the design shown in Fig. 138. This was intended for highly volatile western coals, hence the arch over the grates. By proper proportioning this could have been developed into a rapid steamer superior to its predecessors as to freedom of circulation, and all tubes could be cleaned. The design is lacking in steam space and water endurance, and would prime badly. Mr. Bonus tried to overcome these defects in the design shown in Fig. 139, in which the water endurance is made larger by the addition of the forward drum, and the steam is dried by the over-comer tubes connecting that drum to the disengaging drum. The traps in these over-comers are objectionable, and the water in the forward drum not only has no circulation in it, hence is stagnant and might cause pitting, but its surface would fluctuate up and down as the rate of driving of the boiler changed, as in Fig. 102. Mr. Bonus arranged to feed into this front drum, and if the water contained foamy matter, that would reduce or destroy any superheat imparted by the over-comers. Notwithstanding these deficiencies, this design represents some advance in the right direction, and all that was necessary to develop it into a boiler superior to any other preceding it was to perfect the proportions and details, though Mr. Bonus carried the development no farther. Yet others were quick to seize upon what he had started, but without giving credit to him.

351. Fig. 140A shows a boiler in which the water line is assumed to be at the middle of the rear top drum. Steam is supposed to disengage in each of the larger top drums, and flow through over-comers which dry and deliver it to the small drum in the center, which contains the outlet nozzle. The area through the tubes in the three banks, starting from the rear top drum and traveling downward, is in the proportion of 3 to 8 to 3, therefore the slowest water velocity in the circuit is in the bank over the fire, which is precisely the opposite of what it should be, per Sect. 52. This produces a high speed in the down-comers, where it should be slow so as to precipitate the solids; a slow speed over the furnace where it should be high to sweep away the steam bubbles as fast as formed; and a throttled pass in the top bank, which is made worse by the very slight angle of inclination of the tubes. In consequence, this throttling, together

with the strong upcast from the tubes over the fire, will cause the water to fill the front drum and pass into the over-comers, precisely as it does in Fig. 105, and further shown by Figs. 115 and 116. This defeats the whole object of the design, hence further analysis is unnecessary. The deficient furnace volume, and the scheme of baffling which does not permit radiant heat to strike the tubes, are evident.

Fig. 140B is an English design which in effect is only a modification of Fig. 140A, because the water in front drum B will rise to the level of the top over-comer tube, though the designer

a successful boiler, and it has appeared in sundry forms for a decade, both in Europe and in America, without surviving long. But to those deficient in knowledge of underlying technical principles this scheme looks attractive, so it is frequently resurrected, claimed to be new, and used to start another industry which cannot survive. For a typical case of a revival of this scheme see U. S. Patent No. 1,259,660, subject "Steam Boiler," to Thos. T. Parker, March 19, 1918.

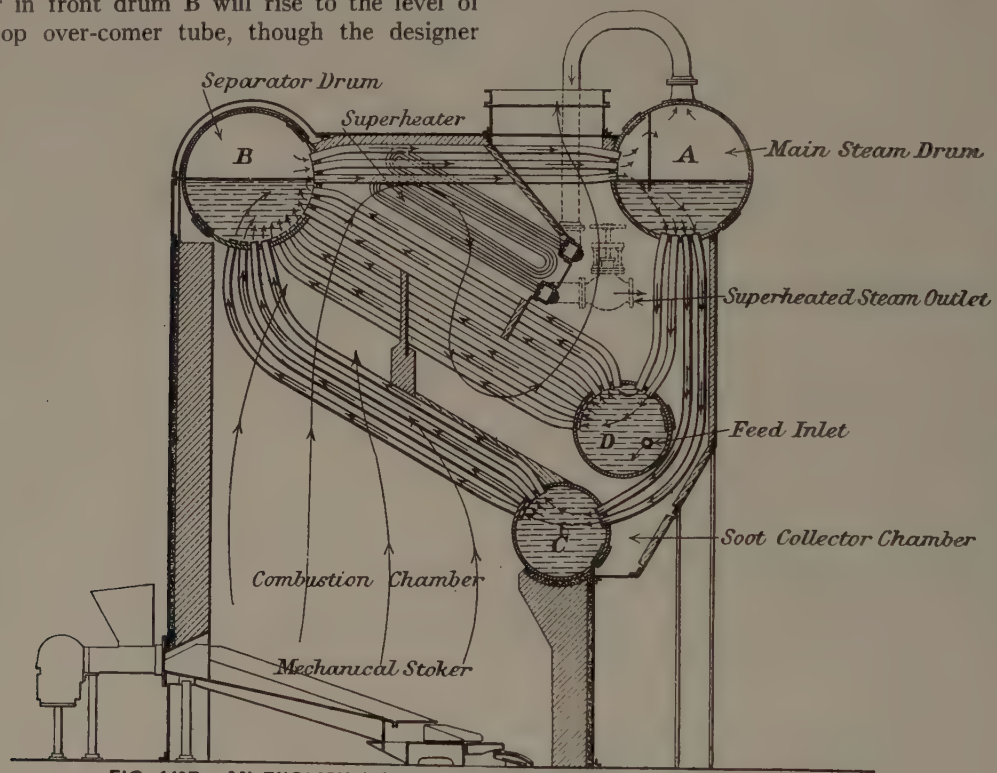


FIG. 140B. AN ENGLISH DESIGN WHICH CONTAINS THE SAME DEFECTS AS FIG. 140A AND INTRODUCES SOME NEW ONES

appears to have had no suspicion of that fact. "The separating drum B working in conjunction with the main steam drum A, acts as an efficient stabilizer with the result that even at the highest rate of evaporation priming is eliminated." Reference to Sects. 84 to 86 will reveal the fallacy in this statement.

The extra mud drum D appears to serve no purpose other than to increase the complication, though the designer uses it as the point of entrance for the feed. The error in that arrangement is shown in Sect. 137.

For the reasons above shown the arrangement per Figs. 140A and 140B can never qualify as

352. These cases further show the extent to which unsatisfactory operation of boilers is largely due to difference of water level in the various drums. It is therefore apparent that few understand or even suspect the causes producing such difference of level, and such lack of knowledge has caused many failures. See Sects. 52 to 56, 62 to 66, 187, 188, etc.

353. This is shown by Fig. 141 which bodily appropriates the design shown in Fig. 139 with some changes to avoid the traps in the overcomers. Here the inequality of area through the tubes in the various banks in Fig. 140A has been avoided, and the steam is disengaged in the rear

top drum, then passes through the over-comers into front drum E to which is attached the steam outlet. The water in drum E was *supposed* to be at the same level as in the rear top drum, but it is not, as will now be shown. Drum E is connected to the drum below it by pipes A, B, and C, and the bottom of the water column is connected at D. Refer to Fig. 105 which shows that the strong upcast in the front bank of tubes causes a wide difference of water level in the three drums. Precisely the same result occurs in this case, hence the water piles up in drum E, from which it cannot escape, and it so encroaches on the steam space that it at times not only reduces or destroys any drying imparted to the steam by the over-comers, but if under these conditions there is a sudden drop of pressure in the steam main, water will be pulled out into the main. The same force which holds this water up in the drum also affects the level in the glass, hence the indication of the latter shows nothing whatsoever as to the position of the water in the rear top drum of this boiler.

354. As developed in the discussion of Fig. 105 this action varies with every change in the rate of driving of the boiler, and in consequence the water level in both the glass and drum E will seesaw with every change in that rate. Hence if the firing be suddenly stopped the water in the glass will instantly drop out of sight.

355. The consequences of such action are particularly troublesome and dangerous. When boiler feeding is in progress the *rate of steaming always decreases,* and more so in proportion as the feed is colder. "Tests with a flow meter have shown that a boiler *can have its output reduced almost to zero* in a small fraction of time by the introduction of cold feed water."—R. H. Rice, in A. S. M. E. Transactions, Vol. 33, p. 591. This correspondingly reduces the force of the upcast in the front bank of tubes, hence the water level in both gauge glass and drum E falls; the operator, not realizing this action, continues feeding until the glass indicates a level opposite the center line of drum E; when the feed stops and *the boiler begins to steam again at full rate,* the force of the upcast is restored, hence the water rapidly rises again both in the glass and the drum E, and this action may cause a slug of water to be carried out into the steam pipe, and *simultaneously the high water alarm often begins to blow,* and keeps blowing until the boiler evaporates sufficient water to reduce the entire level by the amount *which the upcast causes it to rise after feeding stopped!* It is evident that as the alarm blows after feeding is stopped the operator cannot control such action, or stop the blowing unless he lets some water out of the boiler, which not only wastes heat, but is impracticable.

356. When the water falls below the point at which the alarm blows the level in the rear drum may be lower than the feed pipe entrance, in which case steam entering this pipe will cause a severe water hammer. Also most of the up-comer tube ends will become uncovered, and each tube will project a stream across the drum as in Fig. 76, hence cause priming. Because of this and the troubles above named some inspectors compel the installation of a second gauge glass

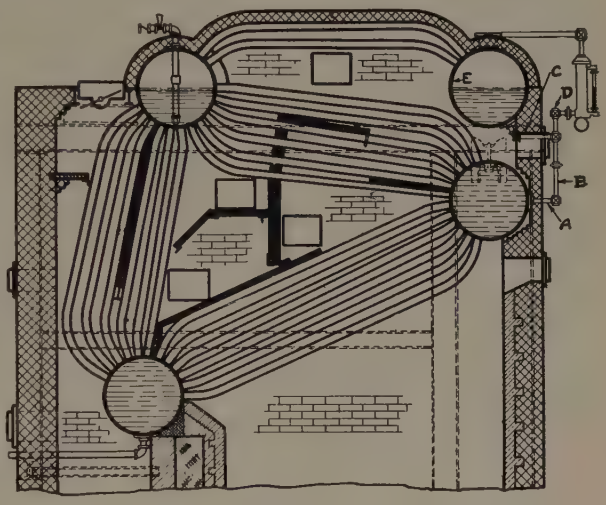


FIG. 141
A MODIFICATION OF FIG. 139 WHICH PRODUCES ERRATIC AND RAPIDLY SHIFTING WATER LEVEL

directly connected to the rear top drum so as to show just where the water stands in that drum.

357. This case is interesting as illustrating how a lack of adequate technical knowledge results in futile cut-and-try schemes, and vain groping after a solution which a qualified designer would see at a glance. To remedy the above stated deficiencies the next scheme tried was to replace drum E by a header made of 8- to 12-inch steam pipe and acting as a terminus for the over-comers, and to connect the top pipe of the gauge glass to the rear drum, as shown in Fig. 142. This does not prevent the action of the upcast in showing a false level in the glass, or the seesawing of the water in the glass; *it halves both the steam space and water endurance of the boiler, and therefore doubles the tendency to*

prime in the disengaging drum! In consequence slugs of water will be pulled through the over-comer tubes, and to stop that the next thing tried was to lower the water line so as to get more steam space, but this introduced *two more troubles* to replace the *one* which the method was expected to overcome:—(*a*) It reduces the endurance surface to a small fraction of its former amount, and when the water falls below the level of the drum the endurance surface shrinks to the sum of the cross sectional area of the tubes in the rear bank, and the up-comer tubes discharge into the steam space with great velocity so that

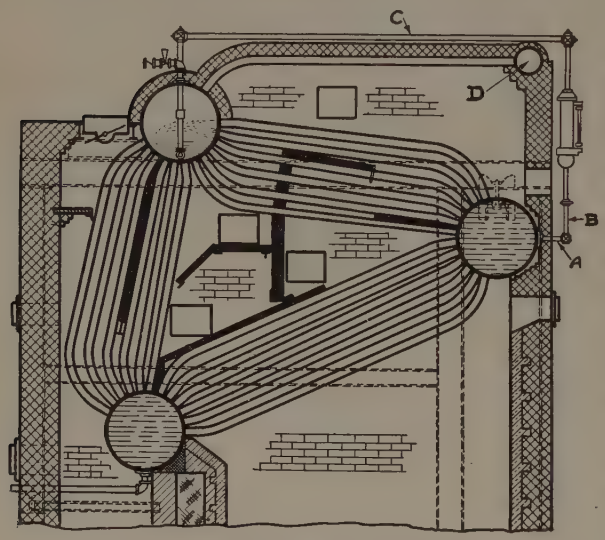


FIG. 142. A MODIFICATION OF FIG. 141 WHICH INTENSIFIES ITS DEFICIENCIES

priming is excessive, as the effluent splashes clear across the drum just as in Fig. 76. As confirming this, a case recently came to our notice where a boiler arranged as above described, and vociferously claimed to deliver *superheated* steam, actually gave steam containing over 4% of moisture, even when tested by an expert and after repeated attempts had been made to reduce the moisture content. (*b*) This scheme exposes the end of the feed pipe, so the feed entrance was next transferred to the mud drum,* which illustrates a typical case of "out of the frying pan into the fire," because in such case the freshly entering water passes directly into the tubes over the fire, without any opportunity of previously depositing its solids, hence burning of the tubes due to deposit of incrustation is largely increased. This we have noted from actual observation of plants where both methods of feeding are used. This scheme also accelerates corrosion of the parts, hence is never permitted by engineers who understand the principles involved, for reasons very fully given in Sects. 134 to 137.

A further deficiency of this scheme is that the pipe header fills with mud swept over by the steam.

358. It was finally seen that with the gauge glass connected at its bottom to the drum below, the water was constantly surging and did not give a true indication of the level in the drum. Hence once more a change was made and both connections of the water column were then attached to the rear drum. These connecting pipes are frequently 20 feet or more in length, and besides their unsightly appearance and danger of stopping up with mud, the water in them becomes cold, hence of a different specific gravity from that in the boiler, therefore they do not necessarily give a true indication of level. See Sects. 62 to 66.

359. Some boilers of this general design have been equipped with an additional element in the rear consisting of two drums into which are crowded the greatest possible number of tubes, and the arrangement is called a "preheater" and is intended to serve as an economizer. Figs. 62 and 127 show such arrangements. These again illustrate the danger of embarking on devices without adequate technical knowledge to foresee how they will act when at work; this scheme is old, and not only has it made no headway, but in several installations such preheater pitted and corroded so badly that it had to be removed. Sects. 201 to 225 show why this was inevitable, and the precaution necessary to permit such arrangement to be used with safety.

360. Great claims were made for the above design as to unrestricted circulation, but it overlooked the fact that there are *two media which have to flow, namely,* both the water *inside,* and

*One maker driven to this method of feeding because of the deficiencies of his design tries to camouflage the error by saying:—"It is easier to blow scale out of mud drum than to bore scale out of tubes." This adroitly insinuates that by such feeding the solids are dropped into the mud drum as soon as the water enters, whereas in fact the entering water is quickly pulled into the tubes over the fire and the deposits occur there just where they greatly accelerate the burning of tubes, and the difficulty of removal of such deposits. See Sect. 120.

the gases *outside*. Figs. 141 and 142 show that the gas flow is badly throttled just where its passage should be free, namely above the furnace where the gas volume is greatest owing to its high temperature, so this arrangement frequently has to be altered. Also the flat tile baffles are objectionable because soot gathers on top of them.

361. It is clear that the general design of pressure vessel of Fig. 141 literally appropriates that of Bonus in Fig. 139 except as to the point of feed entrance. It is further clear that just in proportion as it departed from the original its performance deteriorated. In the later arrangement shown in Fig. 142 it is lacking in both steam space and water volume, and especially so in water endurance surface, and all of these deficiencies are often intensified by use of drums of small diameter to reduce the cost. In consequence *this design requires everlasting vigilance to prevent low water, and it primes so excessively that even when equipped with a superheater it often pulls over water if run at even moderate rating.* A scheme tried with a view of overcoming such priming was to cause excessive throttling of the steam just before it entered the top drying tubes. To do this, the ancient and discarded scheme of plugging tubes as used by Boyrie, Sect. 262, Anderson, Sect. 263, and Solignac, Sect. 272, was tried out, and plugs with a hole through them about one inch in diameter were driven into the tube ends in the steam drum. While this somewhat reduced the trouble it could not overcome it. *But this method is extremely dangerous and liable to cause the boiler to explode!* Reason:—the safety valves were on the *forward header,* therefore these throttling devices *are between the boiler and the safety valves,* which is contrary to law and should subject one guilty of it to prosecution, because any stoppage of the holes in these plugs by scale would immediately result in producing a closed vessel without any safety valve protection whatever. This is not an imaginary danger because we have seen cases where the opening through such plugs was filled solid with scale. If the safety valves are placed on the rear drum the over-comer tubes will be short-circuited, hence liable to burn.

362. Another scheme tried was to replace the front pipe header in Fig. 142 by a small drum containing a longitudinal partition dividing this drum into two compartments: the over-comer tubes discharged into one compartment, to which was connected one end of a horizontal U-tube whose other end terminated in the second compartment: this additional U-tube surface was expected to dry and superheat the steam.

It is evident that with such arrangement mud would aggregate in the first compartment and gradually fill it, precisely as it does in the pipe header in Fig. 142. Therefore this arrangement does not remedy the troubles above pointed out.

363. There is but one real cure for the deficiencies of design above shown, *and that is so to rebuild the boiler as to remove such defects!* In evidence of this, some who have purchased this design have found its performance so unsatisfactory that KIDWELL BOILER CO. was retained to redesign and rebuild the boilers, provide them with drums of ample capacity, and revise the tube system so as to operate on correct principles.*

364. These cases strongly illustrate Lucke's statement in the preface that less is known of boilers than usually supposed, and Bertin's statement as to the difficulty of designing a satisfactory boiler, with the implied consequence that such task should be undertaken only by those who by long training, extensive experience, ripened judgment, and full appreciation of the serious consequences of failure, are qualified to undertake such work.†

365. Fig. 143 shows a boiler which is evolved from Fig. 102 by lowering the top front drum below the water line and increasing the number of tubes connecting it to the middle drum sufficiently to operate on the ring-circuit principle. The middle and rear drums are connected by over-comer tubes which are swept by some gas in order to dry the steam. The steam outlet is placed on top of the rear drum which is set somewhat higher than the middle drum. The other features are apparent from the figure.

366. So arranged, this boiler has better circulation than Fig. 102, but for the reason given in Sects. 296 to 299 *the water line in the two top drums cannot be at even approximately the same level when the boiler is steaming, and will seesaw as the load fluctuates.* In fact, this action will be even more pronounced than in Figs. 102 and 105 for the reason set forth in last paragraph of

*Since this was written, 6 boilers thus reconstructed have gone into commission, and are now doing satisfactory work with complete elimination of priming.

†Because of lack of space this foot note is placed on bottom of next page.

Sect. 314. Accordingly, the rear drum will lose its water even more rapidly, and in consequence the danger of overheating, blistering or bulging the rear drum will be somewhat increased. It

As a feed water heater this rear bank is open to the same objection as given in Sect. 330, hence this arrangement is falling out of use for reasons given in Sects. 303 and 311.

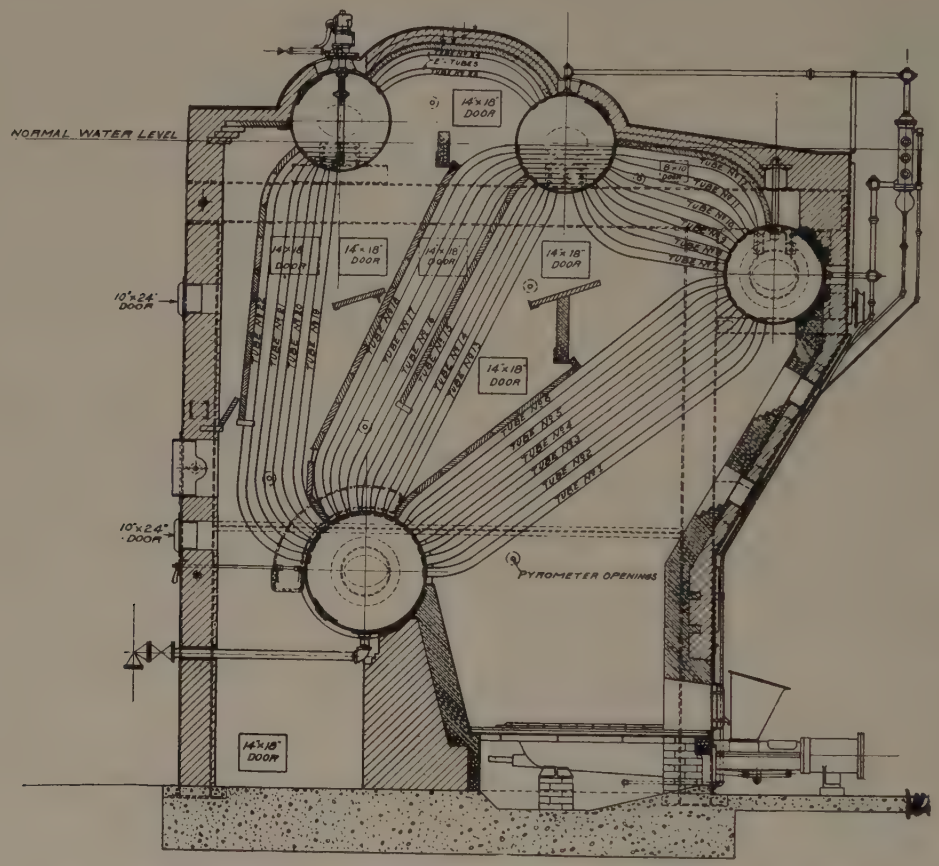


FIG. 143. A MODIFICATION OF FIG. 102 WHICH FAILS TO ELIMINATE THE UNEQUAL LEVELS AS SHOWN IN FIG. 105

further introduces a serious source of error in fuel tests as shown by last part of Sect. 299.

To prevent water hammer in the feed pipe when the rear drum is empty, a pan to act as a

The foot note below applies to the reference on bottom of preceding page.

†An apt illustration of this is found in *The Generation of Power* by Dr. D. S. Jacobus in *Journal of Franklin Institute,* December 1910, thus:—"Many so-called new cycles for the production of power have been brought out from time to time. In most cases these cycles serve as an illustration of the old adage, that a *little knowledge is a dangerous thing.* The inventors often work out pages of thermodynamic formulae to uphold their views. In other cases the problem is dealt with in broad generalities, heat units being handled as if they were packages that could be moved at will from shelf to shelf and so made to pass from one part of the apparatus to the other without loss, no consideration being given to the amount of surface required to effect the transmission or to the radiation losses. In some cases heat is assumed to be transferred from one part of the cycle to the other, no proof being offered that the interchange will be possible, that is, from a hotter to a colder medium. *Still other inventors actually build machines only to find that this is the most expensive way of becoming convinced that they are mistaken.* I have had to examine many such schemes and in most cases it could be readily shown that the cycle was at variance with the well known laws. Cycles that do not conflict with the laws can usually be shown to be impracticable when the sizes of the parts necessary for an actual machine are computed and the radiation losses allowed for. If we could but find a way of disposing of heat at a temperature lower than that of the surrounding objects, we could utilize all of the heat of the ocean or the atmosphere to develop power. Many of the schemes advanced in the so-called new cycles are equivalent to this and the inventors have wasted their energies in striving for the impossible."

water seal for this pipe is necessary, precisely as in Fig. 110, and how this aggravates the propensity to priming, and causes danger of cracking drum plates and building up scale like a stalagmite are all shown in Sect. 321. For the same reason as given in Sect. 353 and Fig. 141 the up-cast action of the front tube bank will drive the water up into the water column connection so that the height in the column may be widely different from the level in the top drum.

For fluctuating or intermittent loads this design has the same deficiency as pointed out in Sects. 298 and 299. The fact that all heat absorbed by the tube bank connecting the middle top drum and mud drum is swept into the front tube bank has the same effect in reducing the overload capacity of this boiler as set forth in Sect. 317.

367. The overcomer tubes between the top drums are of smaller diameter than the main boiler tubes and the gas sweeping these tubes is of such low temperature that it has little drying power. The slight superheat possible is likely to be lost, however, if the feed water is foamy, and it will certainly be lost if the steam pressure suddenly drops, because then the "pop-bottle" action as described in Sects. 85 and 86 will occur in full force from the tubes below, precisely as in Fig. 102, with results identical with those described in Sect. 304. This result is inseparable from the use of the rear bank of tubes patterned after Fig. 102, which scheme is now being abandoned as stated in Sects. 303 and 311.

While it is often claimed for this design that it delivers superheated steam, such tests as we have seen show only from 3 to 7½ deg. of superheat, and that even this moderate amount is not certain is evidenced by the fact that in one case where in April, 1923, tenders were invited for three 1100 HP. boilers and the quality of the steam had to be *guaranteed,* one maker of this design specified that up to double rating the steam would be *dry* (not superheated), and for higher ratings contain ½% to 1% of moisture. Contrast this with what is shown in Sect. 513.

Further, in this design as in Fig. 102 the space available for installing superheaters is so limited that the amount of superheat that can be got is less than is frequently desired, and the equipment is difficult to get at for cleaning, inspection or repairs.

368. The gas baffles in the figure show a soot lock over the mud drum. With gas passes as arranged in the figure the flow of water and gas in first part of the middle tube bank and rear bank are both contrary to Sect. 132.

369. It therefore appears that while this design embodies a few changes from Fig. 102 it eliminates not one of its serious defects, hence represents no substantial advance.

370. Fig. 144 from *Power,* Feb. 28, 1922, shows another design evolved out of Fig. 102 by submerging the *middle* top drum, and thus reversing the scheme used for developing Fig. 143, with distinctly inferior results. While Figs. 102 and 143 each contain *one bank* of tubes in which

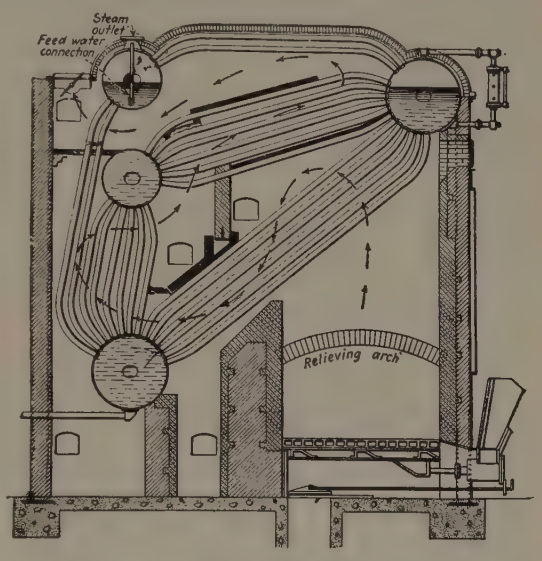


FIG. 144. ANOTHER VARIANT OF FIG. 102

steam is generated and compelled to flow downward, this arrangement doubles that deficiency by having *two* such banks!

This scheme incorporates the obsolescent rear tube bank as used in Fig. 102 with all its disadvantages as shown in Sects. 303 and 311, with the additional deficiency that the feed pipe has open ends discharging into the steam space. The top tubes are intended to dry the steam just before it passes out. Wet steam will therefore result. This trouble will be aggravated if the water is foamy. Unless this feed pipe be provided with a mud pan or water seal like in Fig. 110, there will be a severe water hammer in the pipe, and if this device is provided the consequences will be as described in Sect. 321.

The gas courses in this arrangement are not good. The flow of water and gas in the tubes

over the fire is contrary to Sect. 132. The rear bank of tubes will be largely short-circuited by the gas. The gas sweeping the drying tubes will not be of sufficient temperature to have much drying effect. Finally, as the rear drum and top of the tubes will, when operating, be as shown in Fig. 105 and contain no water, the arrangement is clearly dangerous and subjects the drum to grave danger of overheating and failure.

The horizontal gas baffle across the rear tube bank is particularly objectionable as causing a soot lock. It is almost impossible to make such baffle tight, and it interferes with freedom of replacing such tubes.

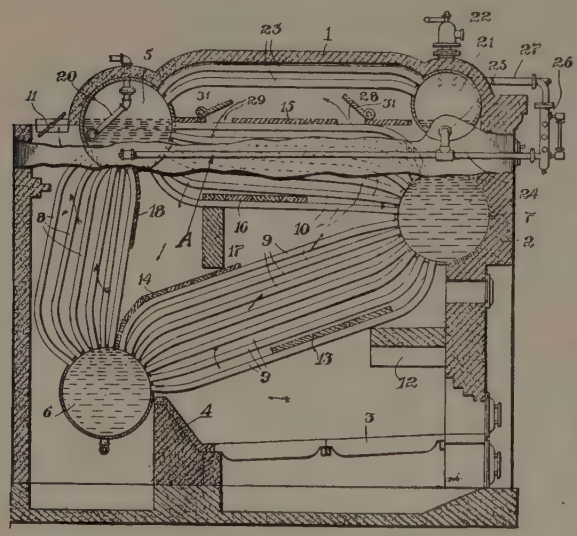


FIG. 145. DESIGN BY W. T. LINTON

371. Fig. 145 shows a far more intelligent effort to eliminate differences in water level in the drums than any other we have seen. This was worked out by Mr. W. J. Linton. Here an equalizing pipe A connects the two drums and a continuation of it serves as the bottom connection of the water column. The deficiency of this arrangement is that there is no circulation in this connecting pipe when placed as shown in the figure, hence the water in it gets cold, therefore the level in the glass is not altogether accurate, and as the boiler expands when heated up this pipe does not expand with it, so that the connections leak badly. Further, the size of this connection is wholly inadequate to the service it is expected to perform. But the design is clearly an improvement over its predecessors, and is capable of development.

372. Sundry other designs have been attempted, but with even less success, hence it is unnecessary to discuss them. The net result of all these attempts has been to demonstrate fully that while the ring-circuit principle is the only one which completely complies with the requirements as to perfect circulation *in the main water circuit, that feature alone cannot produce a boiler equal to present day requirements,* since in addition thereto means must be found to insure adequate steam and water volumes, proper water endurance surface, dryness of steam, and absolutely steady water level. How all this is accomplished is shown in Chapter VI.

373. This and preceding chapter fall far short of their purpose if they fail to prove:—(a) That most boilers now in use function in a way neither foreseen nor suspected by their designers, nor appreciated by their users, and that many of them run dangerously near the limit of safety; (b) The truth of Bertin's statement in Sect. 10 that boilers:—"are by no means of such simple construction as is often supposed. At present there is no problem in the design and construction of engines which approaches in difficulty those encountered in boiler design"; (c) Lucke's statement in Sect. 7:—"that the steam boiler is the *least understood* today of all the important structural elements" in power plants; (d) That boilers in use today confirm the warning of Prof. Marks in Sect. 12 that:—"The designer must learn these laws (of nature), and *all of them* that effect the particular case he has, before he can effect safe and general solution"; (e) That the production of a successful boiler is an extremely difficult task which requires far more than a checker-board exercise in shifting the elements of some existing boiler which has achieved a measure of success into positions sufficiently different to avoid patent conflict or conviction of direct copying, and supplementing such shifting by *guessing* what the new aggregation of parts will do, instead of *knowing* through application of exact technical knowledge. "What we need is first *a knowledge of the facts;* second, the intellectual vision to see its application to the practical problem; third, sound critical judgment, capable of discriminating between the foolish and the useful; and finally the patience and courage to put the idea through to a commercial success."—A. S. Dwight, President's Inaugural Address, Am. Inst. of Mining Engineers, Feb., 1922. Also see footnote, Sect. 364.

V. "Requirements of a Perfect Steam Boiler," and Who Should Select and Operate It

374. Before one can design a boiler which approximates perfection or determine whether an existing design does so or not, he must have a clear understanding of all the elements which are necessary in such a boiler, and the preceding chapters were written for the specific purpose of pointing out and illustrating such elements. A study of these will disclose the following:—

375. There is no such thing as a *perfect* boiler, since if there were it would answer every possible purpose, and improvements or further development would be impossible. All designs except this perfect one would be discarded, and there would be nothing left for us to learn. The exact contrary is true, and less is known about a boiler than almost any other piece of machinery in a power plant. The reason is that the requirements to be met by a boiler are so numerous, fluctuate so rapidly, and so conflict with one another that every design is necessarily an adjustment between these conflicting elements. Thus M. Bertin 24 years ago wrote:—"With so many conditions to be fulfilled, it is not astonishing that the ideal boiler has not yet been discovered."—*Marine Boilers*, p. 22. This is confirmed by Melville's statement in Sect. 11.

376. To illustrate, if large capacity must be installed in a small space, the water-, steam-, and furnace-volume must all be small, which is extremely objectionable for reasons already given. No matter what requirement be named, it will be found to conflict with some other important detail, hence a compromise must be made between such opposing elements, and that compromise which produces the greatest total return upon the investment will constitute the best boiler. To attain the knowledge and skill necessary to make such compromise long study and experience are necessary, and it can be gained only by actual contact with boilers themselves. To get that necessitates personal sacrifices which few are willing to make. In the words of Kreisinger:—"The main reason for tardiness in boiler improvement lies in the reluctance of educated engineers to do the dirty and disagreeable work involved in boiler tests." In consequence, much of the current belief as to boilers is in error as this book proves.

377. Our knowledge of physics is constantly enlarging; manufacturing, metallurgical, and chemical processes are always improving; designs of plants are steadily advancing;—in fact, progress is constant in every line of mechanical activity. In consequence, machines, processes, and methods which represented the highest development several decades ago are now usually antiquated, and therefore have either been replaced by others into which every subsequent improvement has been incorporated, or are causing their users losses which, if realized, would compel their immediate condemnation and replacement by others which are up to date.

It requires too wide a stretch of the imagination to believe that the period which produced the vast number of revolutionary inventions now essential to our daily life was so barren of the peculiar brand of mechanical brains required for designing boilers that no advances in this line were made during this unequalled era of mechanical development! Yet this book and further study of the whole field will disclose the significant fact that such improvements have all been in *mechanical or constructive detail!* While the turbine principle, and Stumpf's central port or "unaflow" principle have been developed and successfully applied to prime movers, *not one new principle improving boiler design has been discovered and successfully developed into a practical design!* The design discussed in Sect. 333 does embody a new principle which reflects credit on its discoverer, but for reasons given it probably will not survive. With this solitary exception there is not another design in this book, except the Kidwell boiler, which embodies anything not known by *competent* engineers 40 years ago, though many who undertook to design boilers were deficient in such knowledge as shown herein.

378. Since the requirements for boilers are innumerable no one design can be best for all

uses and conditions. Thus, a design excellently adapted to low pressure steam heating or for boiling or cooking would not be best for operating at high pressures under heavy and fluctuating overloads, nor would a boiler which would be satisfactory for operating a water works always be suitable for driving a rolling mill engine or a mine hoist.

379. Consequently, any list of items constituting a "perfect" boiler is necessarily approximate, and can apply only to a specified range of service and to the period during which it was written, and will require frequent revision as the art of boiler building advances. Yet some writers have attempted to formulate such lists. One may be found in *The Steam Boiler,* by Prof. R. H. Thurston. Another much better known was drawn up in 1875 by Messrs. Geo. H. Babcock and Stephen Wilcox, and this has been so widely copied, quoted, etc., that students and others not posted on the present state of the art are often misled into the belief that it is a species of *ex cathedra* declaration to be accepted as both complete and correct without question, hence it is necessary to clear away such error. This list is probably as accurate as could fairly be expected from the state of the art when it was written, but part of its statements are inaccurate, while many things essential in good boilers *of today* are not even mentioned. To make this clear we reproduce this list of "Requirements of a *Perfect* Steam Boiler," and briefly comment on each one of them.

"1st. Proper workmanship and simple construction, using materials which experience has shown to be the best, thus avoiding the necessity of early repairs."

This is not specific. Some builders use very poor workmanship and claim that it is "proper." Others use very objectionable material, yet claim that it is also proper *just because they use it.* For example, the authors of this list used cast iron headers, and their successors do so today, but few competent engineers sanction such material, and in most countries its use for boilers for power purposes is forbidden by law. This should be done in the United States, and certainly will be when the public realizes the true facts.

"2nd. A mud drum to receive all impurities deposited from the water, and so placed as to be removed from the action of the fire."

This requirement could be observed to the letter, yet produce poor results. Not only is a mud drum necessary, but it is equally necessary so to arrange the water velocity in the circuit that the precipitates are permitted to drop into the drum, instead of being swept into the tubes, as is often done (Sects. 120 to 122), and further to arrange the details so that the blowing off will not start the joints leaking and perhaps rupture the drum, as explained in Sect. 240.

"3rd. A steam and water capacity sufficient to prevent any fluctuation in steam pressure or water level."

The first requirement cannot be met. The steam pressure will fluctuate *some,* no matter what practicable steam capacity be provided, though by good design the magnitude of such fluctuation may be reduced. Water capacity alone cannot prevent fluctuations in the level. In fact, an increase in water capacity may aggravate such fluctuations. Thus, double the length of the drums in Figs. 33, 64, 80, etc., and the difference between the level at the front and rear ends of the drums will double, and as the load changes this will constantly seesaw. See Sect. 58 and Figs. 9 and 100.

"4th. A water surface for the disengagement of the steam from the water, of sufficient extent to prevent foaming."

This statement reflects the confusion of ideas as to what "disengaging surface" really means. See Sects. 78 to 81. Extent of water surface alone cannot prevent foaming, though under certain conditions it may reduce its intensity.

"5th. A constant and thorough circulation of water throughout the boiler, so as to maintain all parts at the same temperature."

This is incorrect. Circulation is essential in order to sweep away the steam bubbles as fast as formed and thus prevent the tubes from burning. Circulation cannot keep all parts of a boiler at the same temperature, as shown in Sect. 53, etc., but it can and should prevent rapid fluctuation of temperature of the parts.

"6th. The water space divided into sections so arranged that, should any section fail, no general explosion can occur and the destructive effects will be confined to the escape of the contents. Large and free passages between the different sections to equalize the water line and pressure in all."

The first statement reflects the now obsolete idea as to "sectional" construction. See Sect.

345. Modern designs do not reduce the steam and water spaces to small volume, but they make the *parts exposed to high temperatures and wear due to erosion of fast moving water small in volume.* The requirement as to "large and free passages between the different sections" is well stated, but seldom met, and of boilers now on the market the header and nipple types are the most deficient in this most important detail, which explains why their circulation can never be other than defective, as shown in Sects. 72 to 77 and elsewhere. In Fig. 102 the impossibility of providing sufficiently free water passage between the front and middle drum helps to produce the result shown in Fig. 105.

"7th. A great excess of strength over any legitimate strain, the boiler being so constructed as to be free from strains due to unequal expansion, and, if possible, to avoid joints exposed to the direct action of the fire."

Well stated, and even more necessary now than when first written, as boiler pressures have greatly increased. The practise today is to use the word "stress" to convey the meaning above expressed by "strain," but the authors used that word correctly for the time at which they wrote.

"8th. A combustion chamber so arranged that the combustion of the gases started in the furnace may be completed before the gases escape to the chimney."

This falls far short of present requirements. The combustion should be completed *before the gases reach the boiler,* and failure to secure such result is evidence of deficient design. See Sects. 162 to 174.

"9th. The heating surface as nearly as possible at right angles to the currents of heated gases, so as to break up the currents and extract the entire available heat from the gases."

This is far from true. For anthracite and non-volatile fuels such arrangement may work well, but for highly volatile fuels the parallel pass is better. In Figs. 4 and 5 the boiler which showed the best results had parallel gas passes.

"10th. All parts readily accessible for cleaning and repairs. This is a point of greatest importance as regards safety and economy."

Correctly stated, and cannot be improved upon.

"11th. Proportioned for the work to be done, and capable of working to its full rated capacity with the highest economy."

Properly stated for 40 years ago, but far out of date now. A boiler which cannot do better than this will attract few buyers. What is needed now is a design which can develop highest economy when operated far above rating. That is why rapid circulation is now imperative, though decades ago it was not important.

"12th. Equipped with the very best gauges, safety valves and other fixtures."

Correct as far as it goes.

It is therefore clear that the above list is neither sufficiently specific, nor always accurate, and that it omits many most important requirements.

380. It is questionable whether any list that is fairly complete can be drawn up within reasonable length, though we believe that by summarizing the deductions from the preceding chapters it is possible to formulate the requirements better than has yet been done. Accordingly, *without any intention of being dogmatic or claiming infallibility* we submit the following, and invite suggestions as to how it may be improved in future editions of this book. We omit the word "perfect" for reasons above shown. This summary is based on the self-evident principle that in engineering, as in art, perfection of the whole requires perfection of all its component parts.

Essentials of a Good Steam Generator.

381. A boiler consists of three parts:—(*a*) The pressure vessel, or kettle; (*b*) The furnace; (*c*) The housing or setting. It is not usually realized that each one of these must be developed to the same degree of perfection as the others if the efficiency of the combination is to be high, but such is the case. This must be clearly understood and acted upon if successful results are to be obtained.

Each of the above named parts must have the essentials as listed below.

382. The Pressure Vessel:

(1) The design must be as simple and direct as possible, and everything operate toward securing the maximum efficiency of capital, rather than any subordinate efficiency.

(2) The number of parts must be reduced to the smallest consistent with obtaining the desired results. Such parts are preferably spherical or

cylindrical in shape so as to obviate use of stayed surfaces. If the latter are used they must be so arranged and braced that they cannot distort or produce non-figurable stresses resulting from steam pressure or temperature changes.

(3) All secondary or combined stresses of the kind shown in hanger P, Fig. 70, must be avoided.

(4) The number of joints to be broken and remade during cleaning and inspection must be brought to an irreducible minimum. These joints must be such that they can be remade without special and expensive gaskets or packings, or scraping and refitting the surfaces, or requiring repeated trials before they can be made tight.

(5) The pressure vessel must be made of material having high tenacity, great ductility, and of such uniform texture and composition that physical and chemical tests can prove its fitness *before it is used*. Such material must be capable of enduring without injury all the mechanical operations necessary during fabrication of the boiler, and for further security of the buyer this material should be made to comply with specifications or rules of competent and reliable authorities, such as Boiler Inspection and Insurance Companies, or the American Society of Mechanical Engineers' or other good Codes.

(6) The configuration of parts must be such as not to require the metal to be so frequently heated during fabrication as to impair its quality or to undergo operations which thin or weaken the metal at vital points, as sometimes occurs with forged headers or similar parts of complicated and irregular shape.

(7) Regardless of Codes, Insurance regulations, or any other authorities, cast iron falls far short of the ductility needed in boiler materials, hence should never be permitted in any vital part of a boiler intended to produce steam for power plant purposes.

(8) The circulatory system must be so designed as to produce each and every one of the following results:—(*a*) Cause a positive circulation which is not subject to reversal; (*b*) Cause a sufficient speed of flow to prevent stagnation and pitting; (*c*) Make the greatest water speed in the circuit occur in the tubes directly over the fire and in the up-comers conveying the steam; (*d*) Cause in such tubes a water speed which at any rating at which the boiler can be operated will sweep the steam bubbles from the tube surface as fast as formed, so as to prevent steam locks and burnt tubes; (*e*) So arrange the tubes that from the point where the maximum quantity and temperature of heat are encountered over the fire the sectional area through the circulating system will not be materially *decreased*, but will remain constant or somewhat *increase* from that point up to when the flow enters the disengaging vessel; (*f*) Prevent steam slip and reduction of circulation (see Sect. 51) by continuing every tube in the final up-comer bank until it terminates in this disengaging vessel without intervention of headers, nipples or other throttling elements; (*g*) Compel the water to flow with respect to the hot gas as defined in Sect. 132.

(9) The feed must enter at the highest practicable point, as nearly as possible behind the up-comer outlets, join the water circuit where the flow is the slowest, travel the maximum possible distance before entering the tubes over the fire, and drop its sediment into the mud drum just before entering these tubes. See Sect. 133.

(10) The method of feeding must be such that the entering water is *uniformly distributed across the entire water circuit* so as to prevent concentration of impurities in parts of the circuit. See Sect. 231.

(11) A mud drum of *ample volume* must be provided and so placed that it is not subjected to furnace temperatures, and so designed that its upper portion constitutes *an integral part of the main water circuit* and forms the terminus of that portion of the circuit in which the velocity of flow is slowest, so as to produce the result specified in (9) above.

(12) The steam storage space must be sufficient to prevent so sudden a drop of pressure as to cause priming.

(13) The water volume must be sufficient to store enough heat to prevent the pressure from dropping fast enough to interfere with satisfactory operation of the engine, or produce an upheaval of the water which will cause priming. See Sects. 83 to 99 and 304 to 309.

(14) The water endurance surface must be sufficient to prevent a rapid sinking of the water line at any rating at which the boiler may be operated, and in particular this surface must *not decrease as the rate of driving of the boiler is increased*. This is of supreme importance.

(15) The steam must be disengaged in one compartment, and delivered into the outlet noz-

zle through another compartment which is not directly connected to the main water volume of the boiler in such a way as to permit an upheaval of water in the outlet compartment when the pressure in it suddenly drops. The steam passages connnecting the disengaging and outlet compartments must be so arranged that while the steam is passing through them it will be dried and somewhat superheated, since otherwise the outgoing steam will necessarily be wet. See Sect. 88.

(16) The design must be such that regardless of the rating at which the boiler is operated the water surfaces everywhere will be at *substantially* the same level, so that seesawing of the water line with each change of load is obviated.

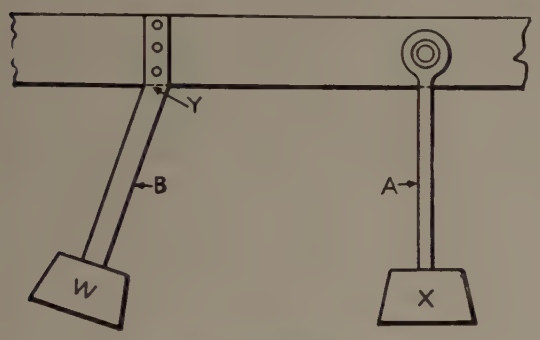


FIG. 70. REPEATED.
FOR DESCRIPTION OF STRESSES SEE SECT. 243

This result is possible only when the boiler operates on the Ring-Circuit principle (see Sect. 346) and not always then unless the other details of design are correct, as shown in Sects. 351 to 372.

(17) A water gauge glass or equivalent so attached that it shows the true water line regardless of the rate at which the boiler is operating. The general design must be such that when the gauge shows water at the proper level, *no part of the entire water surface can vary from that indicated by the gauge to a degree which can endanger the boiler or cause operating troubles.* This is of supreme importance. See Sects. 62 to 66, 353 to 358, and 366.

(18) The parts subject to wear through erosion of fast moving water, or to overheating because of scale accumulating through neglect must be made small so as to localize the effect of failure of such part, and be capable of quick and easy replacement without requiring the sacrifice of other parts.

(19) Every joint, rivet, tube end and other portion of the interior must be accessible and visible for inspection and cleaning, and the design be such that the boiler can be completely cleaned in the shortest possible time which should not exceed 24 to 30 hours in emergencies.

(20) Temperature variations in the vessel must be limited to those due to difference in boiling point due to difference in head (see Sect. 53), and the structure so designed that it can expand so freely that such temperature changes cannot produce stresses which distort or endanger any part of the structure.

(21) The tube system must be such that any tube can be removed and replaced without pulling it through a tube hole, and it must be possible to replace any tube without sacrificing other tubes.

(22) The vessel must be supported entirely independent of the setting.

383. The Furnace:—

(1) Must be designed to suit the particular kind of fuel to be used, and have sufficient volume to insure the combustion of that kind of fuel to the degree of completeness previously decided upon.

(2) Must have sufficient height to permit burning the volatile matter to the requisite degree of completeness before the gases reach the boiler tubes.

(3) Must be equipped with grates, stokers, or burners adapted to the fuel and of sufficient capacity to handle efficiently the quantity of fuel necessary to develop the maximum rating at which the boiler is to be operated.

(4) Must be of such shape as to impart the maximum percentage of heat to the boiler surface by direct radiation. See Sect. 175.

(5) Must to the greatest possible extent be placed directly *under the boiler,* as distinguished from Dutch ovens or extension furnaces, so as to reduce the extent of side walls, roofs, etc., to a minimum in order to lessen radiation loss, and wear and tear of walls. Arches or roofs between the fire and the boiler surface should either be omitted or reduced to the minimum consistent with (4) above.

(6) Must be capable of quick and cheap removal and repair.

(7) Be provided with an ash pit of such depth that no reasonable accumulation of ashes can cause the grates to overheat from below, and thus warp or fail.

384. The Setting:—

(1) Must be compact and so designed as to convey the gases from the furnace through the tubes so as to sweep over every part of the boiler heating surface, and prevent external leakage of gas or internal leakage of air.

(2) Be of such form as to be least subjected to cracking from temperature changes, and made of material having low heat conductivity with small coefficient of expansion.

(3) Be provided with a counter-balanced damper of ample area placed in a box or casing securely anchored to the boiler framework and supported independently of the brickwork.

(4) Be provided with only such other openings as are necessary to permit quick access to the interior, the said openings to be provided with doors which can be kept tight. A sufficient number of such doors must be arranged to open automatically and release the pressure due to a gas explosion within the setting.

(5) Be so arranged both inside and out that soot, dust, cinders, etc., cannot lodge other than in places provided for them and from which they can be easily removed.

(6) Be so arranged that it can easily be repaired or entirely replaced without blocking up the boiler.

(7) Be provided with ample buckstays for supports and a full metal front to afford substantial attachment for doors, instruments and appurtenances.

(8) Preferably have the outer surface encased or well coated with heat insulating material. See Sects. 388 and 389.

385. The Boiler as a Whole:—

(1) Should be selected only after full consideration of not only every preceding item, but also of the kind of service it is to perform, the kind of fuel with which it is to be fired, the method of feeding and burning such fuel, and the character of feed water available.

(2) Be connected to a stack or draft apparatus which can supply at the damper plate ample draft to burn the quantity of fuel necessary to operate the boiler at the maximum rating desired and maintain a slight draft suction over the fire.

(3) It should be provided with all the valves, fittings, gauges, and other appurtenances and instruments necessary for operating it with safety, and indicating whether it is functioning efficiently, and these should be of the best grade and of a weight and strength adequate to the pressure to be carried.

The last statement is vastly more important than generally realized, and deserves more than passing notice. Mr. Victor J. Azbe in *Power Plant Efficiency*, A. S. M. E. Transactions for 1916 says:—"Instruments to show whether a plant is operated efficiently are generally wanting. In boiler rooms 10% to 20% of fuel, *and more in some of them*, is wasted chiefly from lack of indicating devices to detect losses. Too much guessing is done in the average power plant, which is, in part, responsible for the miserable results obtained."

It would be ludicrous, were it not so serious, to note how men who cheerfully maintain an accounting department for purpose of checking up every penny, calmly allow thousands of dollars to be wasted in boiler rooms by purchasing "cheap" and poor boilers to start with, and then refusing to invest enough money to provide the instruments necessary for detecting and preventing such waste. "In the past I have tried to emphasize the fact that the power plant in an industrial establishment must be considered as a *manufacturing plant by itself*. Its output of power, heat, light, etc., should be measured and accounted for just as carefully as the total output of any separate department or of the factory itself."—*Power in Industrial Plants*, by John S. Griggs, Jr., in *Power*, February 7, 1922.

387. The Number and Class of Appurtenances will depend upon conditions, but any boiler expected to produce the maximum returns to the owner should, in addition to the usual steam gauge, water column, etc., be provided with the following attachments. Compare with *Instruments for the Boiler Plant* in *Power*, Dec. 28, 1920.

A steam meter to indicate the output at all times.

A recording steam gauge.

A good feed water meter.

If oil fuel is used, a reliable oil meter.

Accurate gauges indicating the draft at the damper, the furnace, and the difference between these two.

Thermometers or equivalent means to determine the flue gas temperature.

Facilities for placing Orsat or other reliable gas analysis equipment and for making quick connections for use.

A reliable CO_2 indicator.

If a superheater is installed, a reliable thermometer and connection to indicate the final temperature at the superheater outlet, and a good pyro gauge to show the temperature of the saturated steam.

will show *comparative* results from day to day, and if any sudden discrepancy is noted the reason for it can be quickly located, and the necessary correction be made.

388. Hollow Walls and Steel Casings for Boiler Settings. When water tube boilers were

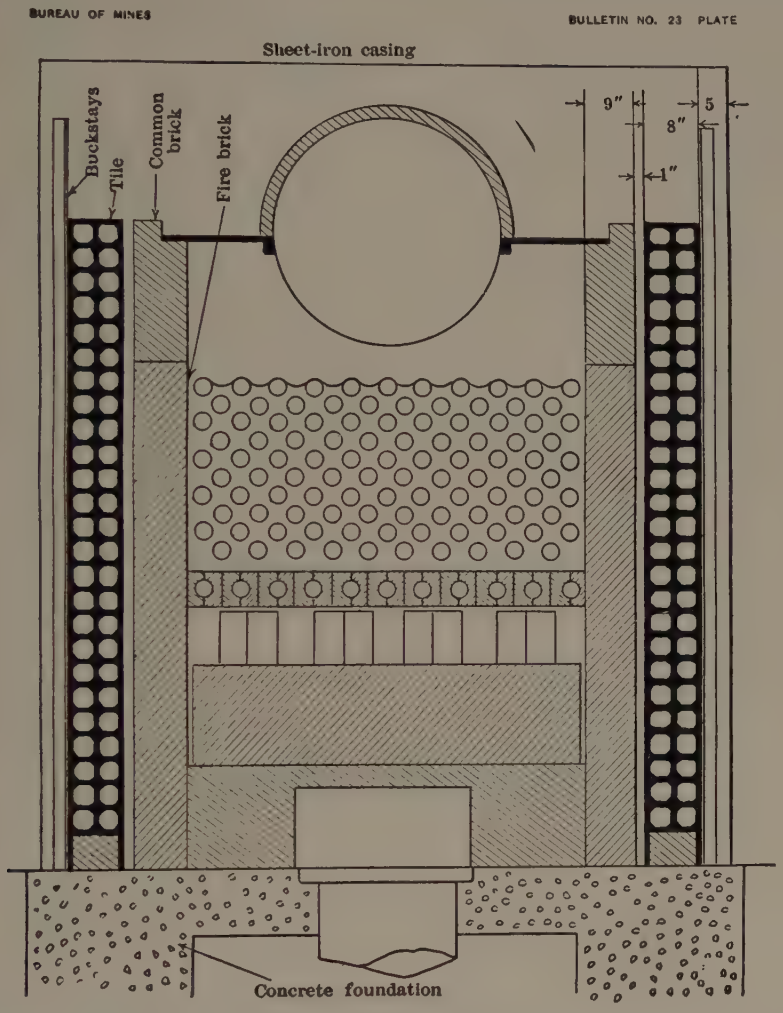


FIG. 146. HOLLOW WALL STEEL CASED SETTING TESTED BY U. S. BUREAU OF MINES

Scales or other equipment necessary to determine with reasonable accuracy the amount of fuel burned.

A station log book in which at prescribed intervals the reading of each of the above named instruments will be entered.

While the above named instruments are neither equal to, nor intended to, indicate results as accurate as can be got by a refined test, they

used aboard ships it was necessary to enclose them in a metal casing to hold the brick setting together when the ship was rolling. Such casings were gradually worked out so as to serve the desired purpose efficiently. Some astute salesman saw an opportunity to develop business by urging such casings for land boilers and of recent years they have been coming into vogue, hence it is pertinent to ascertain whether or not they

are to be recommended. When their purchase is urged much ado is made of the necessity of absolutely air-tight walls. But so far as the *furnace walls* are concerned such tightness is not always beneficial. With certain fuels admission of some air over the fire is essential hence if it leaks through the furnace wall no harm results. See Joerger's article in *Power,* Feb. 13, 1923, page 251.

The U. S. Bureau of Mines investigated steel casings and details are given in Bulletin 23, *Steaming Tests of Coals,* etc., page 23 of which gives the following description of the arrangement tested:—"In August, 1906, a specially designed boiler setting was built and entirely inclosed in an air-tight sheet iron casing. * * * The side wall of the setting consisted of two entirely independent walls, separated by a 1-inch air space. The inner wall was 9 inches thick and was built entirely of fire brick. The outer wall was 8 inches thick and was built of special hollow tiles. These tiles were 10 inches long, 8 inches wide, and 4 inches high, and had two air spaces each 3¼ inches square, running lengthwise. Fig. 146 shows the construction of the side walls.

"The sheet iron casing was placed 5 inches from the outside of the hollow tile so that there were 4 air spaces between the inner wall and the sheet iron casing. The top of the casing was about 4 inches higher than the highest point of the steam drum. In the rear the top was fitted under the sheet iron hood of the stack. In the front and in the rear access to the boiler was had by suitable doors in the casing, which were kept air tight by rubber gaskets."

Results are given on page 298 *et seq.* of this Bulletin. In all, 85 steaming tests were made and compared with 208 tests of boilers with standard brick setting. "The figures show that *nothing whatever was gained in efficiency.* What was gained by the air-tight setting was perhaps lost by *increased radiation.* Furthermore, the temperature of the sheet iron casing on the sides of the boiler *often rose above the boiling point of water,* indicating that too much heat passed through the air spaces in the side walls.

"It is generally believed that since air is a poor conductor of heat, air spaces built into the walls of a furnace will prevent or reduce heat dissipation through the walls. There may be a few instances in which such construction of furnace walls reduces the rate of heat flow through them; however, in most cases the effect of the air spaces is just the opposite. Although heat travels very slowly through air by conduction, it leaps over the air space readily by radiation."

In Fig. 146 the iron casing was extended over the top of the boiler also, which is not usually done.

389. The above facts indicate:—

(a) That hollow walls usually increase the heat loss instead of the opposite. Therefore, it is better to build the walls solid, but if spaces are provided they should be filled with insulating material. A practical objection to such spaces is that the inner and outer walls do not expand together, hence frequently cause *invisible* cracks which produce air leaks.

(b) A steel casing *alone* increases radiation losses. To prevent this it is necessary to insert between the casing and the setting wall a layer of insulating material sufficient to prevent heat from flowing to the casing. Such insulating material is obtainable in the market so prepared that it can be applied to the walls and form an air-tight, elastic and smooth coating which not only meets every requirement as to heat insulating but is also self-sustaining and durable. Under such conditions a steel casing is superfluous or a positive detriment. But if the insulating material is in form of loose fibre or moulded blocks neither cemented together nor tied to the walls, such casing serves as a container to hold the material into place, hence *as a container only* it is advantageous.

Whether such casing is advisable or not is therefore a question to be determined in each case after careful consideration of the conditions to be met and the relative cost of the two methods open for choice. But if such casings are adopted care should be taken to see that they are so designed as not to buckle, distort, and leak because of unequal expansion. This has been one strong objection to such equipment.

Buyers are cautioned against any scheme in which a lining of brick only 9 inches thick is placed between the hot gas and the steel casing. Do not permit less than 18 inches of brickwork on the sides and front, and 13 inches in the rear, otherwise the boiler room will become so excessively hot as seriously to reduce both the comfort and the efficiency of operatives.

This Company furnishes steel casings when requested, and will be pleased to give clients its opinion as to the preferable method for applying

heat insulation to boilers under the conditions reported as existing in each case. But it is pertinent to say here that the above stated facts are becoming recognized so that steel casings are rapidly falling into disfavor among experienced operating engineers.

390. Neither the Boiler nor Any Attachment to It Has Brains! They therefore need brains to direct their operation, which is not as well realized as it should be. See Bertin's statement in Sect. 10 and Melville's in Sect. 14. The operating brains must be supplied by the boiler owner, and the only way in which he can do so is to put the plant under full charge of a man who understands the exact purpose and operation of every appliance installed and will see that they are used, and their lessons constantly applied. He must clearly appreciate that a boiler furnace is a chemical laboratory whose operation depends on many fluctuating factors which must be vigilently watched and controlled if the operation is to be efficient. In this connection see *Fuel Economy and the Human Factor,* in *Power,* May 10, 1921, which deserves careful reading, as evidenced by the following:—"The fact must be thoroughly realized that steam production can hardly be classed as engineering, but is more properly the province of the chemist and physicist. A scientist with a fair knowledge of engineering would be more likely to produce efficient results than an engineer with a limited scientific knowledge. It is safe to say that there is no appliance upon the market that can correctly claim to be foolproof in the sense that its satisfactory operation is entirely independent of the technical skill of the operator. To fulfill such a requirement the apparatus would have to be gifted with the power of determining the class of fuel being used at any time, rate of steam demand and other varying conditions. Technical knowledge is therefore indispensable, whatever type of plant is used."

391. Responsibility for Operating the Plant. Experience proves that the owner should delegate to men of the kind above defined full sway as to operating, and then hold them accountable for results. Both parties to this agreement must realize that for efficient steam making the day has passed when mere thoughtless pitching of coal into a furnace was satisfactory, and that just as for proper blast furnace work each charge must be based on exact analysis, so in firing the operator must understand the technical factors and as nearly as possible work with the same accuracy as in a blast furnace. This can be done only by providing adequate apparatus operated by men who have brains and sufficient enthusiasm to use them.

392. The saving effected by such men is out of all proportion to the expense of securing their services. "The managers of power plants are now appreciating the fact that it pays to obtain the services of high class men in the boiler room, and a much better class of boiler room engineers are employed than formerly. *More can be lost or gained in the boiler room than in any other part of a power plant, and it is false economy to employ other than a capable engineer,* as such a man can save his company many times the cost of his services."—*The Generation of Power, Journal of Franklin Institute,* December, 1910. Also see Azbe's statement in Sect. 593.

393. Who Should Select the Boilers? When a boiler purchase is to be made, *the selection of equipment should be wholly decided by such men.* As shown in Chapter I, the selection of a boiler is too serious an undertaking to be entrusted to individuals who, while possessing the necessary zeal and successful in their various avocations, are confessedly *not skilled plant engineers,* hence are not technically qualified to render a decision on which not only vast financial consequences, but the safety of property and human life constantly depend. It is necessary to point this out because of the prevalent custom of delegating the selection to "a purchasing department whose general attitude is influenced by the thought of dollars to be spent, and who fail to realize the fact that *initial price of equipment bears no relations whatever to the number of dollars that may be lost during the operating life of badly selected equipment—or to the tremendous savings which may be possible by correctly assembled units.*"—F. J. Crolius, Steam Engineer, Carnegie Steel Co., in *Steam Power,* March, 1922. Selecting a boiler is an engineering problem exclusively, while purchasing it is purely a trading problem.

394. Features of an Ideal Boiler Installation. Mr. Victor J. Azbe published in A. S. M. E. Transactions for 1921, under caption *Boiler Plant Efficiency,* so excellent a summary of what a good plant should be that we reproduce it below. It is remarkable that in each of its details it conforms almost to the letter to what has been advocated throughout this book.

"It may appear to some that the boiler with its appurtenances has been developed to what might be called the limiting point; *this, however, is not so. There remains an immense field for experimental research to obtain the necessary data for boiler construction.* The boiler installation of today should embody the following features:—

(a) "A construction permitting counterflow where flue gas will heat the feed water for the boiler which will enter the boiler at as nearly the steam temperature as load fluctuations will permit.

(b) "A combustion chamber sufficiently large and effective throughout to prevent the entrance of any flame among the tubes, thus assuring complete combustion, absence of soot, and proper cooling of the gas.

(c) "Boiler passes which will be effective throughout without dead spaces where there is no gas flow or only little, and in which the draft drop will be the minimum corresponding to gas velocity. The gas velocity will be the highest permissible by the cost of producing this velocity.

(d) "Fuel resistance will be overcome by forced draft.

(e) "The relative location of fire bed and boiler heating surface is to be such that the maximum possible amount of radiant heat will be transmitted to the boiler surface consistent with complete combustion.

(f) "Tight boiler walls properly insulated, probably an air-jacketed furnace, the air from which will be injected over the fire bed at high velocity to aid mixing effect, or passed through the grate in the ordinary way.

(g) "A stoker permitting combustion with no more than 15% to 25% excess air, no more than 1.2% unburned carbon in ash pit, no deposit of slag on the tubes, and these conditions maintained at low and also at reasonably high ratings.

(h) "Scale deposit in the boilers prevented by specially constructed self-cleaning boiler, external chemical treatment of feed water, use of distilled makeup water, filtering of the water in the boiler by re-circulation or by a combination of these methods."

With reference to a "self-cleaning" boiler in (h) we do not know of any such device which is successful. It is to be noted that high speed of water circulation will not accomplish such result, as often supposed. See Sect. 115.

It is proper to state that the publications of Mr. Azbe as referred to in this book merit careful reading by those who seek the truth on some points not well understood, hence the frequent references to them as given herein.

CAREFUL PACKING IS AS ESSENTIAL AS ANY OTHER PRODUCTION DETAIL. THE PHOTOGRAPH ABOVE SHOWS THIS COMPANY'S PRACTISE. ALSO SEE PAGE 258

VI. The Kidwell Two-Flow Ring-Circuit Boiler

395. The preceding discussion has brought out those features essential to any boiler free from the deficiencies of earlier designs. These have been incorporated into the Kidwell Two-Flow Ring-Circuit Boiler, and in consequence it surpasses previous designs in each and every one of the following particulars:—

(a) It produces the most rapid and effective natural water circulation ever obtained, and can reach the limit beyond which it is impossible to go. See Sects. 467 to 469 and 472 to 475.

(b) Its steam generating tubes are so placed with respect to the furnace and gases that liability of overheating tubes is reduced far beyond that of any other design, hence the safe overload capacity is increased in proportion. See Sects. 476 to 481.

(c) In consequence of (a) and (b) it can operate with safety and economy at overloads far beyond the ability of any other design depending on natural circulation, *and has for years been so operating in actual service.* See Sect. 481.

(d) It absolutely eliminates the one great bane of all other designs, namely, a great variation of water level in different parts of the boiler the extent of which fluctuates with every change in the rate of firing, affects the fuel economy (see Sect. 511), causes a surging in the water gauge glass which confuses the operator, and frequently causes overheating and burning of tubes or plates, as explained in Sects. 298 to 300.

(e) Its gauge glass connections are short, direct and properly designed (see Fig. 163), hence the glass always indicates the true level, and the water line does not surge with changes in the rate of driving. See Sects. 62 to 66.

(f) It has ample water endurance surface *which does not decrease as the load increases,* as in other designs, for which see Sects. 58, 59, 298, etc., and Figs. 105, 141, 142, 143, etc.

(g) It not only eliminates the evil of priming, but regardless of how the load fluctuates it delivers steam superheated 5 to 45 degrees, or more, according to the rate and method of firing, which fact alone insures a fuel saving of 5% to 7% or more over any boiler which gives wet steam, as shown in Sects. 513, etc.

(h) It is so arranged that if a higher degree of superheat than the above named is wanted, standard designs of superheaters, as made by this Company or other reliable manufacturers, can be so installed that their headers and tube ends are always easily accessible, and their capacity be such as to produce a degree of superheat higher than can be got by similar installations in other boilers. See Sects. 522 to 527, and Figs. 191 and 205.

(i) It automatically removes from the steam the mud and dirt due to scum on the disengaging surface, and permits such material to be blown out, instead of passing into superheaters and encrusting their tubes and accelerating their destruction by burning, or passing to the engine and augmenting the wear of all rubbing surfaces which come into contact with steam. This highly important feature is exclusive to this design. See Sects. 535 and 536.

(j) It eliminates expansion stresses to a degree never before attained in any good boiler. See Sects. 324 and 539.

(k) It eliminates all tube headers, water legs, multitudinous hand holes and caps and their gaskets, inaccessible nipples or tube ends, parts of complicated shape and uncertain strength, mud drums out of the path of circulation and liable to leakage or rupture when blowing off is required (see Sect. 240), and similar trouble producers and time wasters.

(l) It can be opened, thoroughly cleaned, and closed in as short a time as any other type, and in one-third to one-quarter of the time required by any header and cap type, and at a fraction of the cost of cleaning such types. See Sects. 141 to 146, and 562.

(m) Its maximum water speed occurs at just the part of the water circuit where it is required to prevent overheating of tubes, hence it will lose tubes only when they are allowed to become incrusted, and its rate of tube losses is less than in any other type, and not over one or two per cent of that of constricted circulation types when the two types are equally well cared for. See Sect. 147.

(n) Its *standard* furnace volume is greater than that of other designs, and its arrangement superior as to producing complete combustion of volatile matter and enabling the maximum percentage of heat to be absorbed by direct radiation, which greatly enhances both the fuel effi-

ciency and the capacity. See Sect. 541 (a), and check with Sects. 157 to 171.

(o) It contains no part likely ever to need replacement which cannot be quickly made in any ordinary shop, hence delays for obtaining special parts from the manufacturer are unnecessary.

(p) Its tube system is such that any tube can be replaced without destroying other tubes, and all of its tubes are curved to the same radius so that if a new tube is quickly needed any good mechanic can bend one to suit. In no case does a tube have to be pulled through the tube sheet. See Sects. 410 to 412.

(q) Its setting is such that when boilers are placed in battery the blank heads of the drums are always accessible for inspection—a feature now possessed by no other cross drum design, and most highly recommended by Boiler Inspection and Insurance Companies. Refer to Sects. 430 to 432.

(r) Its setting is so designed that not only are sufficient doors provided to give access to every element, but the interior is so arranged as to provide ample space for a man to reach every part where adjustments or repairs might be needed. See Sect. 436.

(s) The details are worked out to a perfection never before attained, and *standardized* to a degree previously unknown.

(t) The design is so flexible that we have sections worked out to meet any requirements as to pressure, load variations, kind of fuel and method of firing it, for sizes from 150 HP. upward. See Sect. 570.

(u) By reason of the above stated facts this design as to efficiency of Capital exceeds all others, *and it is this particular efficiency which interests the man who pays the bills.* See Sects. 140 and 543 to 600.

(v) The design is fully protected in every detail by U. S. and Foreign Letters Patent, which *we shall protect to the full extent of the law!*

How these advantages are attained will now be shown. We will first explain the constructive features of the design, and then how they operate so as to produce the results above summarized.

General Description and Construction.

396. Origin of the Design. About the year 1893 Dr. Edgar Kidwell, then professor of mechanical engineering at the Michigan College of Mines, Houghton, Mich., reached the conclusion that most of the previously unexplained boiler explosions, as well as the more serious operating troubles with boilers, were due to wide variations in the level of the water in different parts of the pressure vessel, and the rapidity with which these fluctuated as the load changed. The longer the subject was studied and investigated from this standpoint the more the accuracy of this opinion was confirmed.

It was therefore natural to conclude that if a design could be produced which would completely overcome this fundamental deficiency, yet introduce no objectionable features to offset this desired one, such boiler would represent the greatest advance made in steam generator design for many decades.

The solution of this problem was therefore undertaken, but it was not effected until 25 years later. As usual with many inventions the solution was extremely simple, and the great difficulty lay in the finding of it. And also, as is frequently the case, it was found only by departing from the beaten track.

Investigation disclosed that while American and British engineers appear to have given little attention to the subject, French and German engineers had made many attempts to solve the problem. They failed for the very reason that we first failed, namely, their attempts were directed to controlling the *main water circuit* in such way that the difference in water level could be overcome or neutralized. Figs. 9 to 12 show that no solution is possible in any arrangement involving the conventional U-tube circuit in which a gravity head, fluctuating with every change of load, is necessary to drive the water from the up-comer to the down-comer. This method began with the elephant boiler, Fig. 14, but that it is bad engineering is evidenced by Figs. 65, 67, and 80 to 89. Regardless of all argument such as given in Sect. 249 and elsewhere, common sense dictates that to employ means which at best can produce only insufficient speed of circulation and then throttle that circulation, is as inconsistent as to provide a tall stack to produce strong draft and then put a cork into the top of it. See Sect. 471 and footnote for illustration of this reasoning.

It took years to realize this because of adhering to the beaten track, but it was realized at last, and the next step was to eliminate the space between up-comer and down-comer in the U-tube. This had already been done partially in Figs. 68 and 77, but Fig. 76 shows how this

scheme fails unless gagged by a baffle, hence it does not solve the problem. Fig. 100 shows another scheme, and why it fails.

The solution was found in Gurney's ring, Fig. 136, and Fig. 180 and Sect. 462 show how this eliminates the fluctuation of water level in the disengaging drum.

But for boilers to operate at high ratings and deliver dry steam one fatal defect remains—deficiency of water endurance surface and certainty that the steam will be wet. An additional drum will remedy the shortage of water endurance surface, *provided the water in both drums always remains at the same level.* But it will not prevent the delivery of wet steam unless other previously missing features are added.

Elimination of difference in water level and priming proved far more difficult than overcoming surging of water in the disengaging drum. That is shown by Figs. 102 to 105 and all of Chap. IV.

It was therefore necessary to discover a principle entirely new in boiler engineering, namely, how to arrange the boiler so that the main circulation path takes care of *only the generating and delivering of the steam into the disengaging drum,* while a second or supplementary circulation, subordinate to the main circuit as to the amount of water it passes, holds the water surfaces of the two drums at the same level. Sects. 504 to 507 show the details of design, and the effect of it is far-reaching, as stated in Sects. 3 and 508.

To utilize this so as to produce the maximum of results as to fast and unrestricted circulation we have applied it to the design of Gurney, and the Kidwell boiler is the result. To indicate the personal characteristics wherein this differs from others we designate it as the "Kidwell Two-Flow Ring-Circuit Boiler."

Proof that this design is superior to any predecessor is contained in the following pages.

Seldom does any prominent and successful invention appear without bringing out of obscurity a swarm of claimants of the credit of having originated such improvements themselves. Since no exception is to be expected in this case, it is but just to give here honor where honor is due, and to state that the credit for this design in its present perfected form is divided solely between Goldsworthy Gurney, Robert Zell (see Sect. 513), and Dr. Edgar Kidwell. That others who appropriated and profited by the work of the two pioneers first above named have contributed nothing whatsoever to the evolution of boiler herein described is evidenced by Chapter IV, which also shows that he who lacks a deep knowledge of underlying principles cannot, other than in possibly some contributory though unessential mechanical detail, improve on those who have such knowledge.

It is to be noted that the new principle by which this design accomplishes results before unattainable *is not limited, in its application, to this particular form of main water circuit.* It can be applied to sundry header types and thus product a better boiler of that type than has yet appeared. This Company has worked out such application and in due time will offer it to those whose space conditions or other circumstances indicate the use of such design. But the following exposition will be limited to the Kidwell Two-Flow Ring-Circuit boiler.

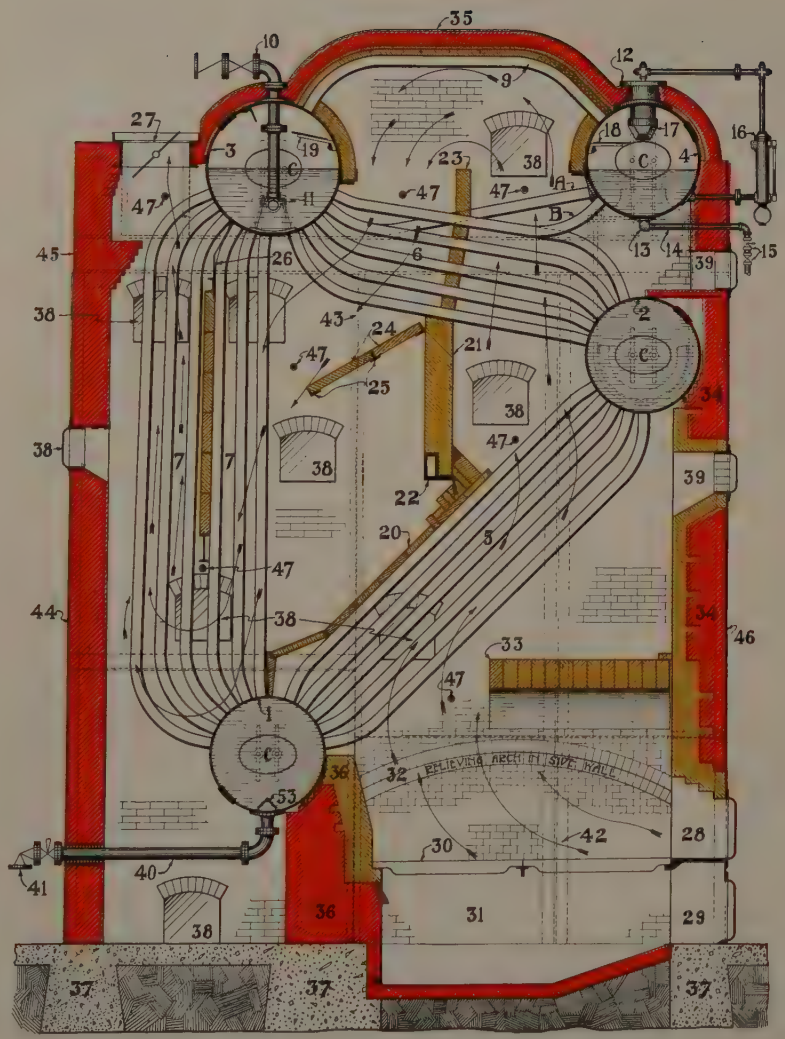
But irrespective of the type of main boiler circuit to which this method is applied, *it once and forever removes from boiler design any necessity of jumping water level and water endurance surface and the formidable list of evils resulting from them!*

Caution! It is not to be assumed from the above that it is possible to produce a design which will maintain the whole or average water level *absolutely unchanged* regardless of the amount of steam being generated. The water level depends on the volume of water plus the volume of steam entrained in it. If now the rate of steam production be *doubled,* the volume of steam in the up-comer will also be doubled, hence the total volume will be increased in proportion, therefore the water level will rise in proportion. This is so in every boiler.

But in a properly proportioned boiler with ample water volume and water endurance surface the change in level *due to the above cause alone* is of no consequence, and in the Kidwell boiler it cannot produce any jumping or surging of the water glass, as shown in Sects. 504 to 508.

397. Figs. 147 and 148 show a side sectional and front elevation of a boiler of medium size set for hand firing, and on the opposite page is a key to the various reference numbers. To obviate need of turning the book when reading the following descriptions Fig. 149 reproduces Fig. 147 on a larger scale for easier reference.

Figs. 150 and 151 show the boiler set with an underfeed plunger type of stoker, and sundry other cuts illustrate settings when stokers of several makes and types are used.



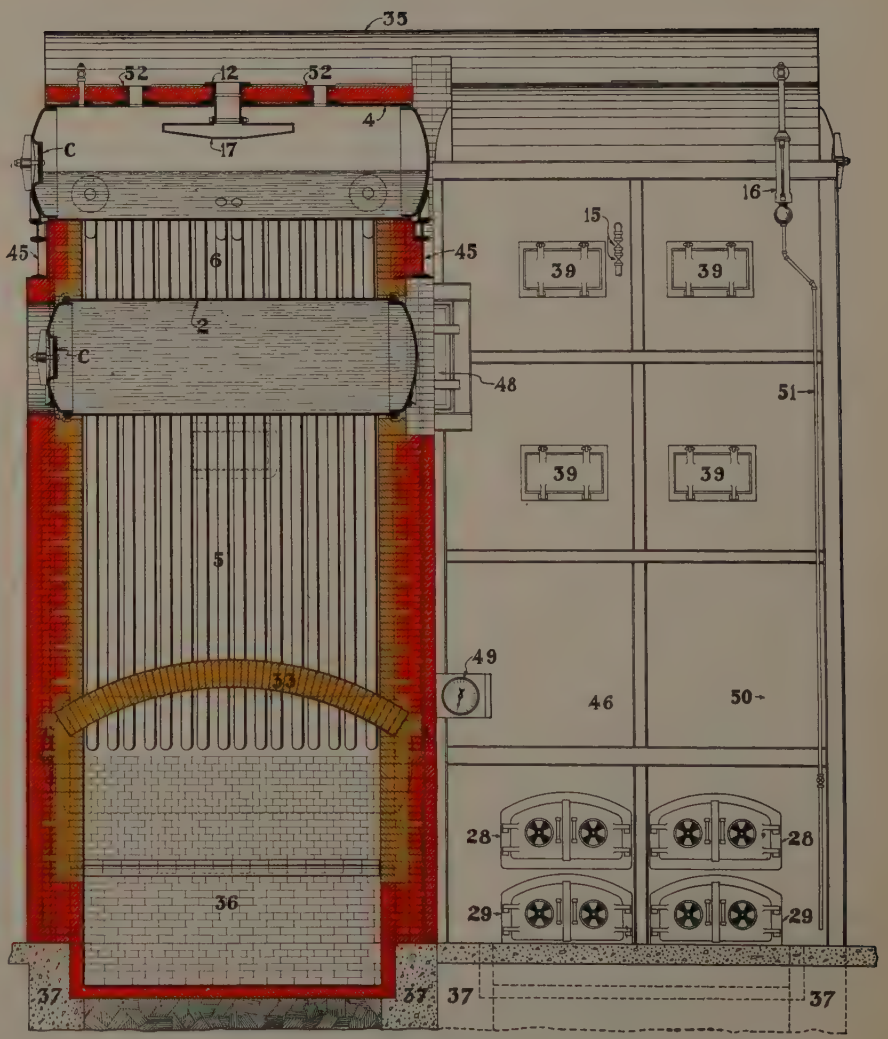


FIG. 147

FIG. 148

THE KIDWELL TWO-FLOW RING-CIRCUIT WATER TUBE SAFETY BOILER, ARRANGED FOR HAND FIRING

Key to Figures 147 to 149

1. Mud drum suspended from the tube banks 5 and 7, and entirely free to move the amount necessary to compensate for expansion of the tubes.

2. Water drum so suspended from above that it is free to move the amount necessary to take up expansion of tube banks 5 and 6. See Figs. 153 and 158.

3. Disengaging drum supported by lugs as in Fig. 157. This drum also receives the feed, as in Fig. 160.

4. Drum which acts as terminal receptacle for steam superheated during its passage through tubes 9. The steam outlet and safety valve nozzles are placed on this drum as shown in Figs. 152 and 161.

C, C, C, C, are manhole covers in drum ends, for details of which see Figs. 155 and 156.

5. First tube bank, which receives the radiant heat and generates most of the steam. See Sects. 449 to 451.

6. Second tube bank, conforming to Sect. 469.

7. Third or rear tube bank. See Sect. 529.

A and B, tubes forming part of the supplementary circuit controlling water level, as shown in Figs. 185 and 188.

9. Steam drying and superheating tubes, concerning which see Sects. 513 to 518.

10. Flanged feed and check valves, and feed pipe entrance.

11. Pipe arranged to distribute feed uniformly through the drum length, as in Fig. 160.

12. Flanged steam outlet per Figs. 152 and 161.

13, 14, 15. Sediment blow-off as per Fig. 163 and Sect. 535.

16. Water column and gauge glass per Fig. 163.

17. Shock absorbing pipe per Fig. 163 and Sect. 414.

18 and 19. Steam deflecting plates or baffles; see Sect. 519.

20. Gas baffles more fully shown in Fig. 164.

21. Cross baffle wall further shown in Fig. 164.

22. Ventilated girder supporting wall 21, as detailed in Fig. 164.

23. Vertical baffle crossing tube bank 6 and constructed as described on Fig. 164.

24. Rear gas baffle of fire clay tiles.

25. Supports for tiles in 24.

26. Vertical gas baffle in tube bank 7.

27. Damper and damper box forming part of boiler framework as shown in Figs. 173 and 174.

28. Firing doors above grate level.

29. Ash pit doors below grate level.

30. Grates.

31. Ash pit.

32. Arch to support side walls when repairs to furnace lining are in progress.

33. Combustion arch over the fire.

34. Red brick portion of setting walls.

35. Brick housing above tubes 9.

36. Bridge wall.

37. Boiler setting foundations.

38. Doors for blowing soot from tubes.

39. Front door for tube removal and for blowing soot.

40. Blow-off pipe.

41. Blow-off valve.

42 and 43. Columns supporting girder 45.

44. Steel angle forming rear column of frame.

45. Girder supporting drums, per Figs. 157 and 158.

46. Steel front of boiler setting.

47. Pyrometer openings in setting walls.

48. Door to opening between drums 2.

49. Steam gauge.

50. Manufacturer's name plate.

51. Water column drain.

52. Safety valve nozzles per Figs. 152 and 161.

Arrows between furnace and damper indicate path of flow of hot gases.

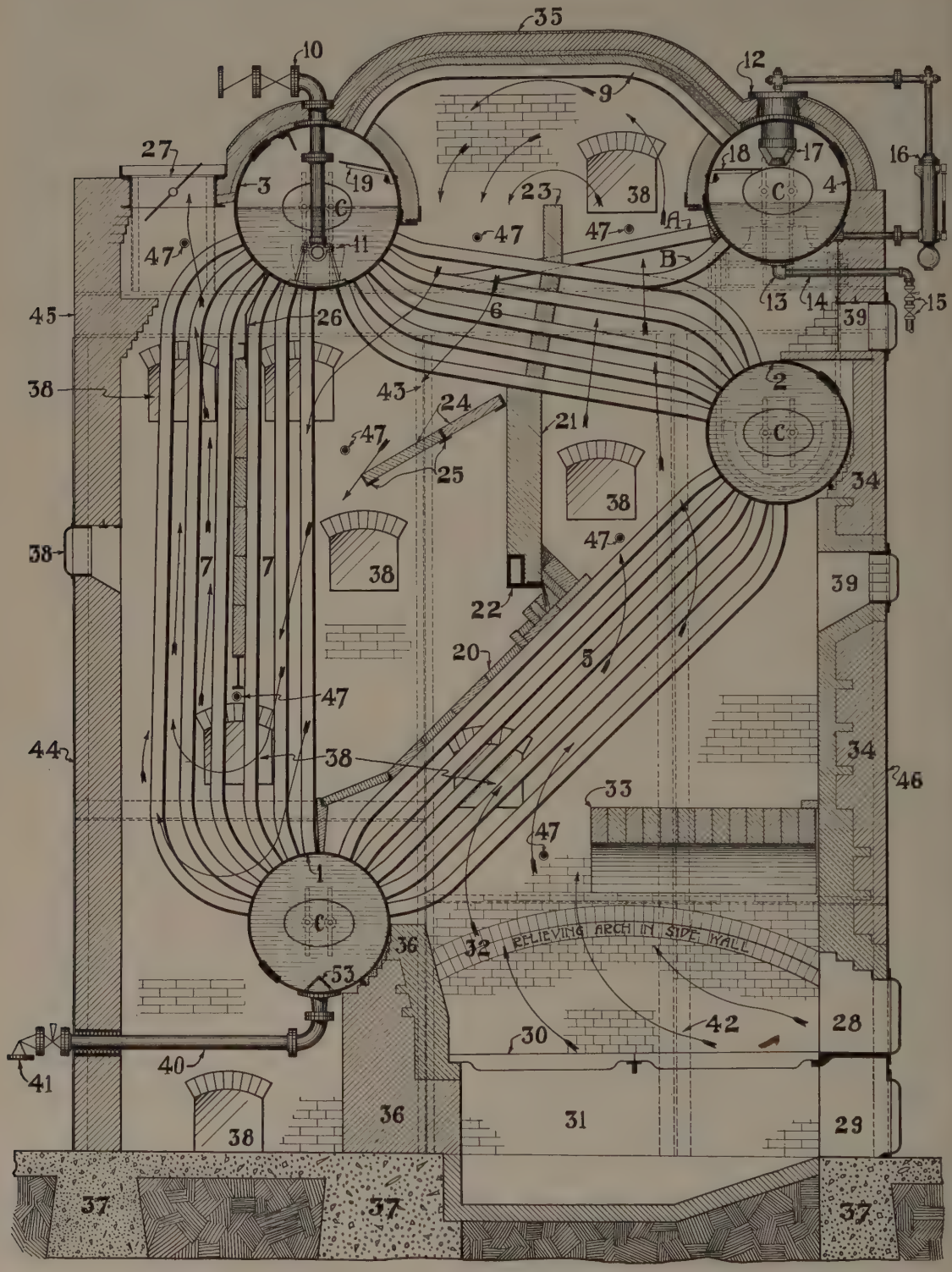


FIG. 149. THIS IS FIG. 147 ON LARGER SCALE FOR EASIER REFERENCE

Key to Figures 147 to 149

1. Mud drum suspended from the tube banks 5 and 7, and entirely free to move the amount necessary to compensate for expansion of the tubes.

2. Water drum so suspended from above that it is free to move the amount necessary to take up expansion of tube banks 5 and 6. See Figs. 153 and 158.

3. Disengaging drum supported by lugs as in Fig. 157. This drum also receives the feed, as in Fig. 160.

4. Drum which acts as terminal receptacle for steam superheated during its passage through tubes 9. The steam outlet and safety valve nozzles are placed on this drum as shown in Figs. 152 and 161.

C, C, C, C, are manhole covers in drum ends, for details of which see Figs. 155 and 156.

5. First tube bank, which receives the radiant heat and generates most of the steam. See Sects. 449 to 451.

6. Second tube bank, conforming to Sect. 469.

7. Third or rear tube bank. See Sect. 529.

A. and B, tubes forming part of the supplementary circuit controlling water level, as shown in Figs. 185 and 188.

9. Steam drying and superheating tubes, concerning which see Sects. 513 to 518.

10. Flanged feed and check valves, and feed pipe entrance.

11. Pipe arranged to distribute feed uniformly through the drum length, as in Fig. 160.

12. Flanged steam outlet per Figs. 152 and 161.

13, 14, 15. Sediment blow-off as per Fig. 163 and Sect. 535.

16. Water column and gauge glass per Fig. 163.

17. Shock absorbing pipe per Fig. 163 and Sect. 414.

18 and 19. Steam deflecting plates or baffles; see Sect. 519.

20. Gas baffles more fully shown in Fig. 164.

21. Cross baffle wall further shown in Fig. 164.

22. Ventilated girder supporting wall 21, as detailed in Fig. 164.

23. Vertical baffle crossing tube bank 6 and constructed as described on Fig. 164.

24. Rear gas baffle of fire clay tiles.

25. Supports for tiles in 24.

26. Vertical gas baffle in tube bank 7.

27. Damper and damper box forming part of boiler framework as shown in Figs. 173 and 174.

28. Firing doors above grate level.

29. Ash pit doors below grate level.

30. Grates.

31. Ash pit.

32. Arch to support side walls when repairs to furnace lining are in progress.

33. Combustion arch over the fire.

34. Red brick portion of setting walls.

35. Brick housing above tubes 9.

36. Bridge wall.

37. Boiler setting foundations.

38. Doors for blowing soot from tubes.

39. Front door for tube removal and for blowing soot.

40. Blow-off pipe.

41. Blow-off valve.

42 and 43. Columns supporting girder 45.

44. Steel angle forming rear column of frame.

45. Girder supporting drums, per Figs. 157 and 158.

46. Steel front of boiler setting.

47. Pyrometer openings in setting walls.

48. Door to opening between drums 2.

49. Steam gauge.

50. Manufacturer's name plate.

51. Water column drain.

52. Safety valve nozzles per Figs. 152 and 161.

Arrows between furnace and damper indicate path of flow of hot gases.

398. General Description. The pressure vessel consists of four drums connected by banks of tubes, the whole being supported on a structural steel framework provided with a neat metal front. The drums contain the necessary openings for the sundry attachments, and the whole structure is enclosed in a neat, compact and well designed brick setting. Thus the design as a whole is characterized by extreme simplicity and complete absence of the usual complicated parts and features liable to derangement.

399. General Construction. Unless otherwise stated these boilers are in the United States constructed in accordance with the Boiler Code of

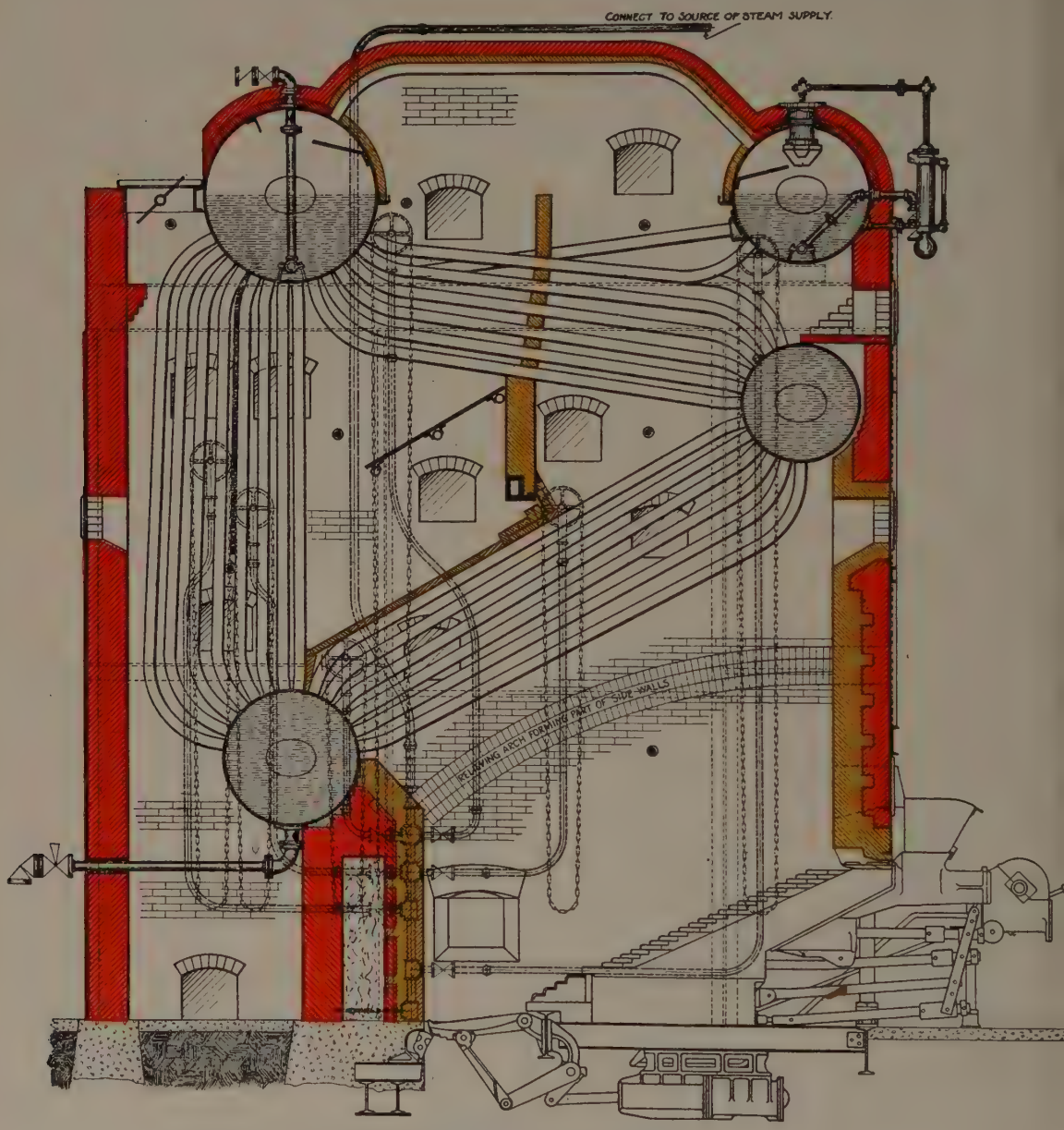


FIG. 150. SECTIONAL SIDE ELEVATION,
KIDWELL BOILER, WITH TAYLOR UNDERFEED STOKER AND DIAMOND SOOT BLOWER

American Society of Mechanical Engineers, and whenever the word Code is hereinafter used it refers to that code unless otherwise specified. The only exceptions to the above statement

are:—(a) Where boilers are built for export or to go to States whose codes differ from the A. S. M. E. Code so that local codes must prevail. (b) While we never make any parts lighter than called for by the Code *we frequently make them*

Boilers built outside of the U. S. are of course constructed to conform to the codes in force where such boilers are to go. Thus, in Canada the boilers are built to conform to the Interprovincial Boiler Code.

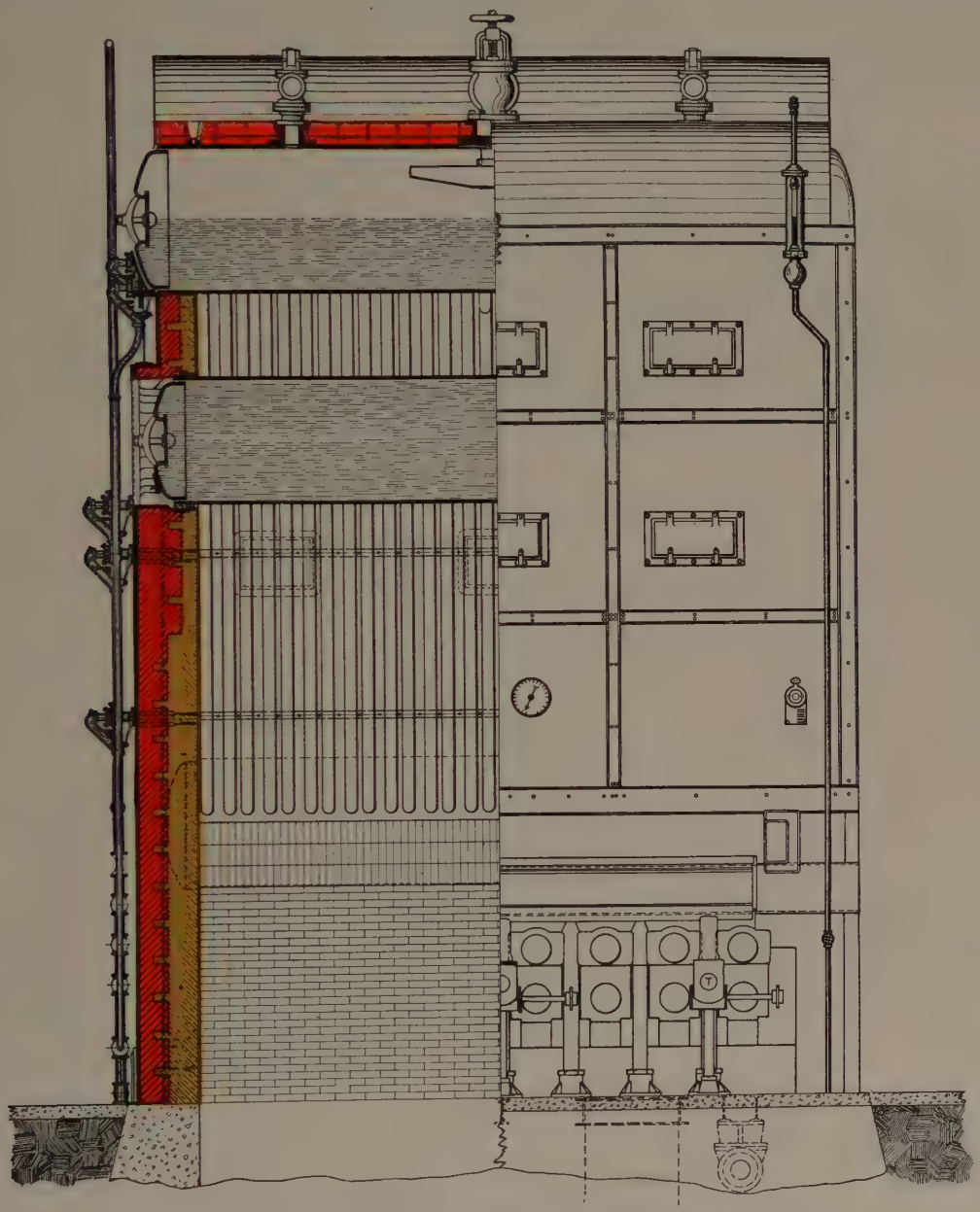


FIG. 151. FRONT ELEVATION AND SECTION OF FIG. 150

heavier where in our judgment it is desirable to do so, as we do not regard the Code as final or infallible; in fact parts of it are extremely inconsistent, and other parts very deficient. See Sect. 401.

400. The Drum Diameters range from 36 to 54 inches according to the size of boiler and class of service it has to perform. The cylindrical parts are made of open heart *fire box* steel, and in sheets extending the entire drum length

so as to eliminate ring seams. Unless the drum is so large that single plates of the necessary size cannot be got, the cylindrical portion is made of but *one plate,* so there will be only one longitudinal seam. This is double butt-strapped always, with the necessary row or rows of rivets. *Lap seams are never permitted by us, as they are a menace to life and property.* All seams may cause a failure at this point unless ample metal is provided, and such failures are far more numerous than commonly supposed. Hence our practise is invariably to make both the blank heads and the manheads thicker than the codes specify. While this increases the cost, it to a *far greater degree increases the security,* which is what we seek, as the Kidwell Boiler is *not a*

FIG. 152. OUTLET DRUM, SHOWING STEAM AND SAFETY VALVE NOZZLES

are so placed that they are never swept by hot gases, hence they cannot overheat.

Figs. 152 and 153 show the general drum construction, and the unusual weight and ruggedness of the fittings are apparent.

401. The Drum Heads are hydraulically dished to proper radius, and of a thickness greater than prescribed by any code or insurance

competition design made simply to sell cheaply, and nothing is spared which is desirable for high operating results, or security of the user. For decisive proof of the correctness of our practise as to this detail see *A Near Boiler Explosion* in *Power,* Feb. 7, 1922.

402. Forms of Manhole Covers. Two kinds of cover are in general use. For land plants the

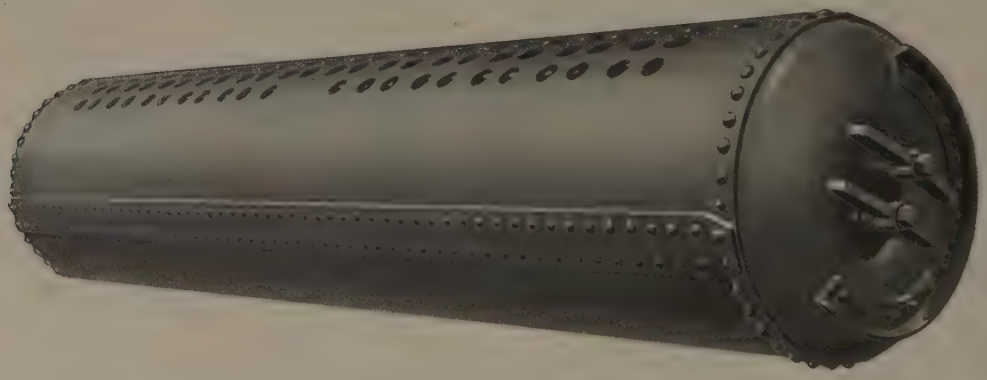


FIG. 153. WATER DRUM WHICH IS SUSPENDED AS IN FIG. 158

regulations. Thus, while by such rules a blank head ½-inch thick is sufficient for a 36-inch drum carrying 200 lbs. pressure, we use a heavier head for such duty, for the following reason:—Refer to Fig. 154; note that the caulking may make in the head an indentation which is shown to an exaggerated degree by A. The breathing of the head under changing pressures

pressed steel cover with pressed steel arch bars, as in Fig. 155, is in extensive use. Its advantage is that it is lighter than any other form, but its disadvantage is that it often has insufficient provision for holding in the packing at its outer edge, hence the packing is liable to blow out under heavy pressures. For this reason Marine Underwriters do not favor or usually accept

this design, but demand the style shown in Fig. 156. In this, the thinner plate riveted to the main cover prevents the packing from blowing out. The arch bars are also stouter and more rugged than the pressed bars, and while heavier to handle, they are much less likely to fail, or to give trouble.

KIDWELL BOILER CO. is prepared to furnish either style, in accordance with the preference of the purchaser, if such is stated at the time the order is placed.

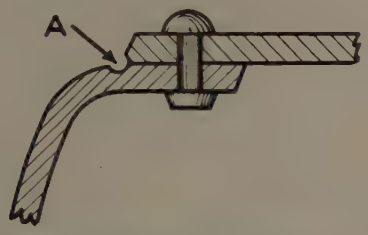


FIG. 154. ILLUSTRATING WEAKENING OF HEAD BY BAD CAULKING

403. Hinged Manhole Covers. There is considerable difference of opinion as to the advisability of hinged covers. Many strongly favor them, and other just as strongly condemn them. In line with its policy to cater to the purchaser's preference in all details in which such can be done without detriment to any essential detail, this Company will furnish either arrangement, if the purchaser states his preference at the time the order is placed. Only the marine pattern, Fig. 156, can be furnished with hinge, however, because if the hinge strap is attached to the form shown in Fig. 155 it is impossible to place rivets in the bottom of the slot into which the holding bolt has to be inserted, and so secure them that a leak is not liable to result. This has been proved by long experience, hence this Company does not sanction such construction.

404. Steel Deflecting Plates marked 18 and 19, Fig. 149, are placed in the top drums, and their function is explained in Sect. 513. They are not *permanently fastened*, but have lugs or ears which slip behind a bar riveted to the drum with distance pieces at intervals so as to form a slot for these lugs, as shown in Fig. 163, hence these plates can be removed instantly and are built in sections to pass through the manholes.

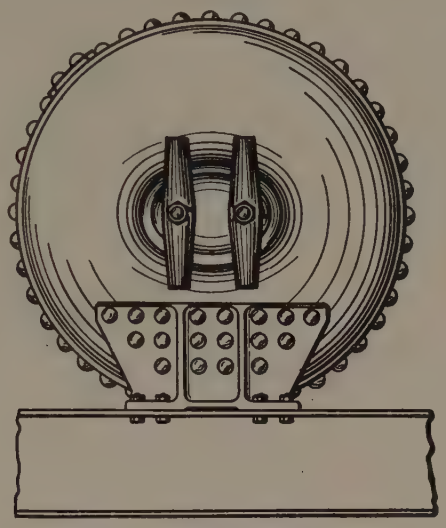


FIG. 157. LUG ON REAR TOP DRUM

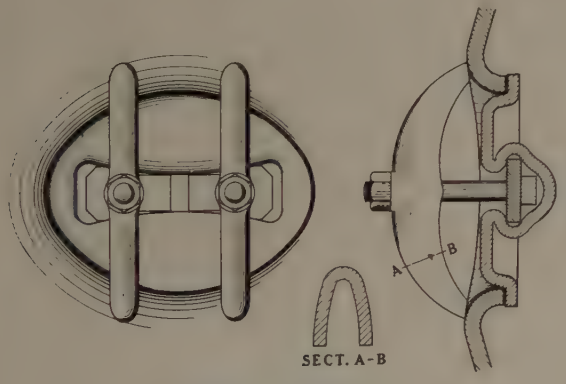


FIG. 155. PRESSED STEEL MANHOLE COVER AND ARCH BARS

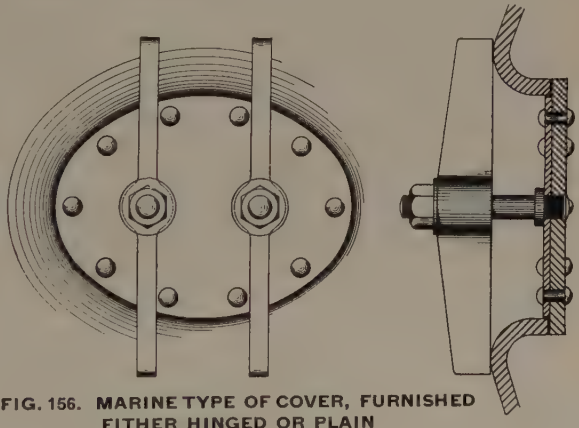


FIG. 156. MARINE TYPE OF COVER, FURNISHED EITHER HINGED OR PLAIN

405. The Lugs Supporting the Top Drums are extremely heavy ductile electric steel castings, which not only exceed in strength the usual forms, but permit the insertion of sufficient rivets to carry the weight with a high factor of safety. They are securely bolted to the frame so that

the drums cannot shift their position and thus strain the piping connections. Fig. 157 shows the lug for the rear top drum and Fig. 158 that of the front drum.

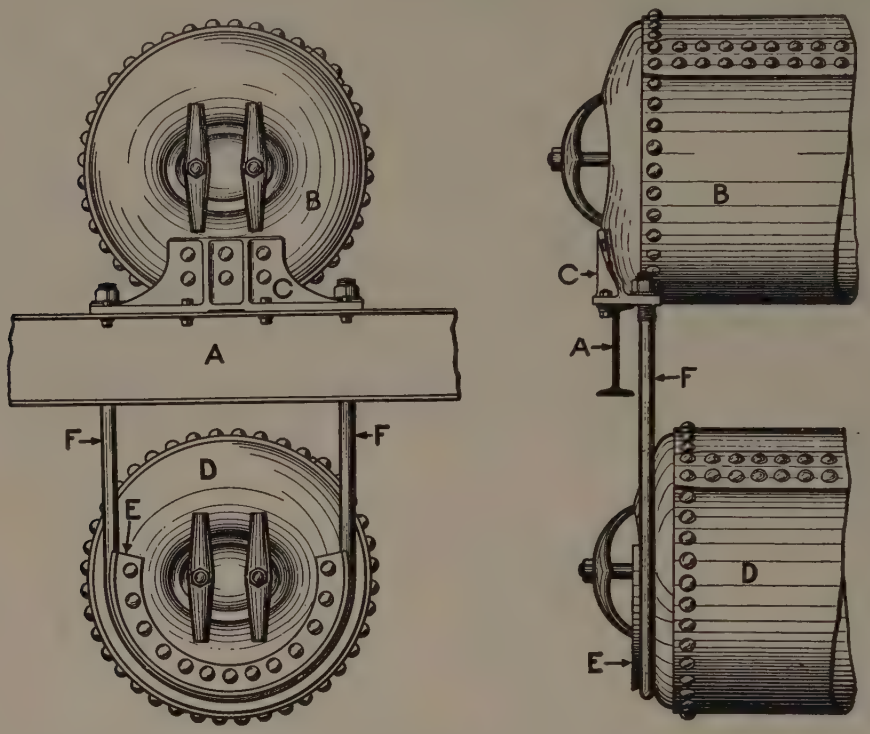


FIG. 158. SHOWING METHOD OF SUSPENDING THE DRUM MARKED 2 IN FIGS. 147 TO 149. PATENTS PENDING

406. The Suspended Water Drum is supported as shown in Fig. 158 in which D is the drum, E an angle secured to the drum head and providing a seat for the U-bolt F which passes through projections at each end of lug C, and terminates in a nut and washer above this projection. Thus the drum can be centered to the exact height desired, and its weight is transmitted to girder A. This construction efficiently stays the framework, as drum B and lug C serve as a tie between girder A and its companion on the other side of the setting, and any tendency of lug C to rotate under the weight transmitted by hanger F presses *inwardly* on the drum head, and thus opposes the steam pressure. Thus arranged, drum D is entirely free to move backward or forward any amount necessary to permit the free expansion of the tubes.

407. The Mud Drum, 1, in Fig. 149, is suspended from the tube banks 5 and 7, hence its movement due to expansion of the tubes is entirely free. The patented method of packing around the ends of mud drum and water drum to prevent air leakage is shown in Fig. 172 and explained in Sect. 433.

408. The Tubes are 3¼ inches in diameter, and are of hot rolled seamless mild steel, or charcoal iron, per purchaser's preference. They are *all curved to the same radius,* with sufficient length of arc to enter the drums normally, and are firmly expanded into the tube holes, and then

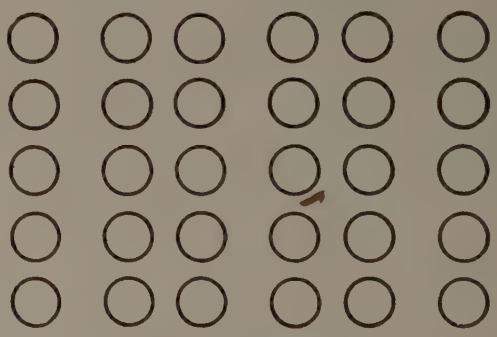


FIG. 159. SHOWING ALTERNATE WIDE AND NARROW TUBE SPACING

flared, and thus there are no recesses between the tube and tube sheet to catch dirt and promote corrosion, as when cast iron headers are used. There are *no nipples, short tubes, or inaccessible or invisible tube ends which can be*

reached only by expanders with jointed handles so that it is difficult or impossible to tell when the expanding has been sufficiently done. On the contrary, every tube end is both visible and accessible so there is no uncertainty as to whether the expanding and flaring is properly done.

409. An item of supreme importance, but seldom thought of by a purchaser until he has had some unpleasant practical experience with it, is the way in which tubes are bent. *A uniform smooth bend cannot be made by use of rollers or parts sliding on the tube.* All tubes in the Kidwell boiler are bent by machinery specially designed and built by this Company, and neither rollers nor shoes sliding over the tube are used, and each bend is smooth and even, and maintains the original bore so that the tube cleaner can pass around the bend as freely as through the straight portion.

410. The tubes in all standard sections of boiler are spaced alternately wide and narrow, as in Fig. 159, so that any tube may be removed and replaced without sacrificing adjoining tubes. When a tube has to be replaced, *it does not have to be pulled through the tube hole!* All that is necessary is to loosen the tube at both ends, push it into one drum sufficiently far to free the end in the other drum, then turn the tube, pull it out through the doors available for that purpose, bring in the new tube in the same way, insert it into the drums, roll and flare the ends, and the job is done. Thus there is no need of scoring or injuring the tube hole so that it has later to be reamed and a ferrule inserted. Contrast all this with Sects. 152 and 153.

The steam generating tubes are inclined and thus prevent the adhesion of a film of steam to the tube walls and the consequent danger of overheating, as illustrated by Fig. 99, and explained in Sect. 287.

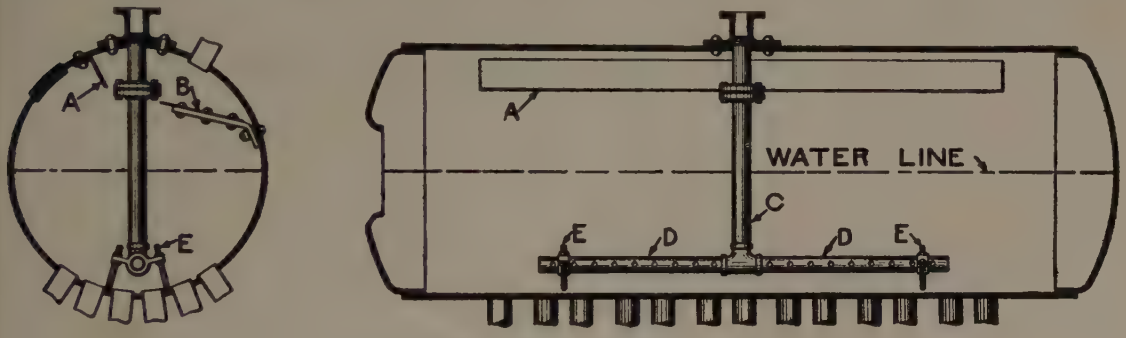


FIG. 160. DETAILS OF FEED PIPE

411. Makers of Straight Tube Boilers even yet try to persuade buyers that curved tubes are harder to clean and to renew than straight tubes. This, of course, is fiction, as shown in Sects. 141, 143, 154 and 155.

412. The Tube Holes are *always bored or drilled out of the solid plate after the drum is riveted up, hydraulically tested, and passed by the inspector.* The scheme of punching the tube holes out of the flat sheet *before rolling* and later reaming them to size, is cheaper, but involves the risk of distorting and perhaps cracking the metal between the holes, hence drums have been known to fail in the ligament from this cause. In fact, we have sold boilers to replace others which have so failed, therefore that method of construction is condemned and shunned by us.

413. The Feed Pipe, 10, in Fig. 149, enters the rear top drum and is shown in further detail in Fig. 160. Pipe C is provided with a flange for quick disconnecting, and divides into two branches D, D, containing perforations as shown, and open at each end as required by most State Codes. Each end rests in an adjustable stand E which prevents any movement due to impulses of the feed pump. Thus arranged, the water is quite uniformly distributed through the whole cross section of the main water stream. This is important, as boilers with parallel longitudinal drums, each with separate feed connection, cannot feed evenly and have burned tubes because the water in one section of the boiler becomes more highly concentrated as to impurities than in other parts which get a greater supply of feed. This increases the tube losses as shown in Sect. 231.

414. A Steam Collecting Pipe and Shock Absorber is usually provided beneath the steam nozzle as shown in Figs. 161 and 163. This is

not a dry pipe, as the steam passing through it is already superheated. Its function is explained in Sect. 519.

415. The Nozzles for steam outlet, safety valves, blow off, and feed are all flanged when 2 inches diameter or larger. Screwed fittings

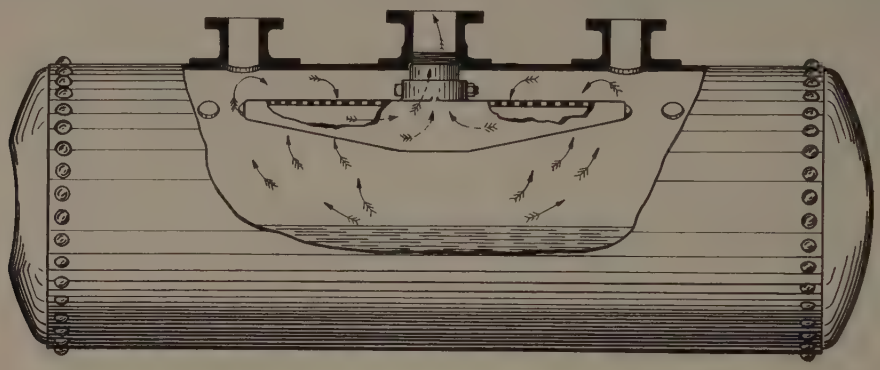


FIG. 161. OUTLET NOZZLE, STEAM COLLECTING PIPE AND SAFETY VALVE NOZZLES

are *cheaper as to first cost only,* since in actual use they are an inexcusable nuisance, *hence we will not supply them.* Neither do we use pads like Fig. 162, which will surely cause trouble when a stud breaks and has to be drilled out.

416. Regardless of the pressure for which boilers are built *we use no cast iron nozzles* as we consider such unsafe. All nozzles are either of forged steel or of heavy ductile electric cast

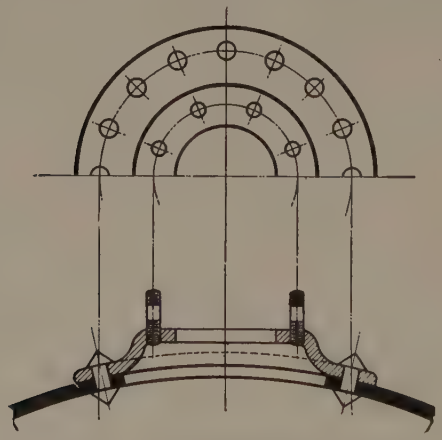


FIG. 162. AN UNDESIRABLE FITTING

steel. We prefer the latter as being heavier and less liable to distort than the thinner forged steel fittings. Note nozzles on Fig. 152.

417. The Water Columns are of Reliance make having high and low water alarms with quick closing try-cocks, unless some other make or arrangement is preferred. The connections are short, direct, and *properly located* as shown in Fig. 163, so that the glass correctly indicates the true level of the water, in contrast to the conditions disclosed in Sects. 62 to 66, 353 to 358 and 366.

418. The Important Appurtenances, such as feed, check, blow off and safety valves, steam gauge, etc., are all of high grade and standard make as furnished by leading manufacturers, and are selected with special reference to the conditions to be met in each case. Whenever possible we permit the purchaser to select such makes of these fittings as he prefers.

419. A Steel Framework supports the boiler independently of the brick work, hence no blocking is necessary when the setting needs

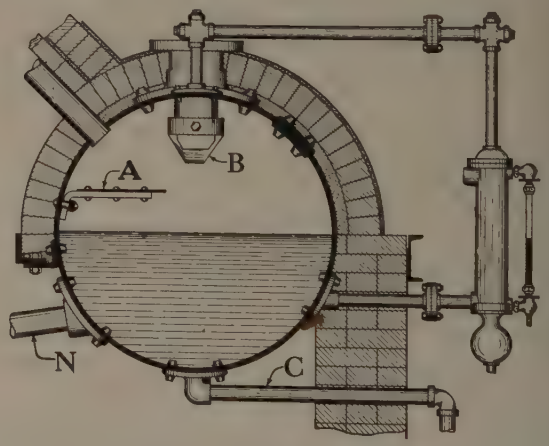


FIG. 163. WATER COLUMN CONNECTIONS, STEAM COLLECTING PIPE, AND SEDIMENT DRAIN PIPE

repairs. Our framework differs from others in that its design has been carefully checked by *experienced structural steel engineers* and its details conform to their standard practise, in contrast to designs turned out by men without

such training. *Standard designs of framework* have been worked out for boilers fired by hand, or by stokers of any type, or by oil, gas, refuse, etc., and we will be pleased to submit proposals to suit any such case.

An important advantage of our design of framework is that the members inside of a battery wall are ventilated as described in Sect. 432.

420. A Full Steel Front is furnished when firing and ash pit doors are required. It is of neat design, and *as plain and flat as possible, so that mouldings, recessed panels, ledges, incongruous ornaments, nameplates, and other dirt catchers are all conspicuous by their absence.*

421. When Stokers are Installed, or waste gases from smelting or heating furnaces, etc., are brought in through ducts entering the forward part of the furnace, the metal front is stopped off at such distance above the floor line as is necessary in each case. The stoker manufacturer shall then furnish an appropriate lower metal front of the full width of the boiler setting, and extending from floor line to the height at which our front terminates. So arranged, *there will be no exposed brickwork in the front, as such brickwork is certain to work loose!*

422. The Brick Setting is compact and simple. The purchaser does not have to obtain any materials which are not found in the open market, and the work can be done by any boiler setter who can follow plain, adequate and lucid drawings and instructions. This will appear from Figs. 147 and 148 and others given herein. Unusual attention has been given to working out details and ascertaining the best material required for each part of the structure so as to make it durable, and to avoid useless expense by placing costly material where it is of no advantage to do so, or unsuitable material in places where the service to be performed requires something better.

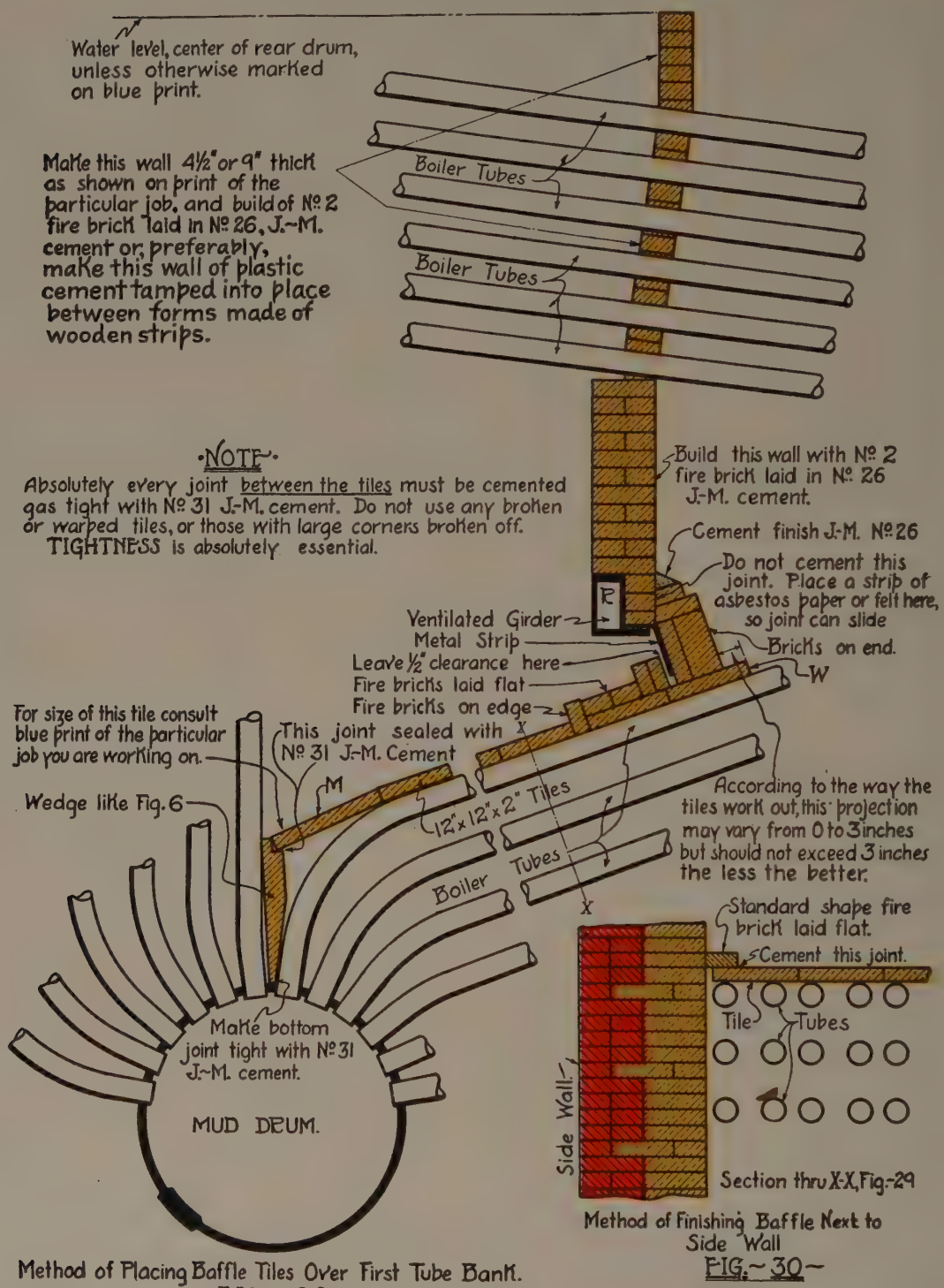
423. Brickwork Specifications and Drawings. It is impossible to give in this book sufficient cuts to show all setting details, but as a part of the service we render our clients we furnish adequately illustrated and lucidly worded specifications and drawings for the construction of the setting, together with a legally drawn form for making a contract for the setting, and an order sheet which purchaser can use when buying material, and thus obviate chance of error and save clerical work. These specifications and drawings cover the subject to an extent never before attempted, but owing to the expense of producing them our rule is to furnish them only to our customers.

We shall, however, explain a few features of the setting to make clear the action of the boiler, and from these the reader can judge as to the thoroughness with which other details have been worked out.

424. The Gas Baffles constitute a detail whose importance is seldom realized. *They perform the same function in a boiler as do the valves in an engine,* and if either are leaky great losses result, therefore every precaution has been taken so to design these baffles that if installed per our drawings they are not only *tight to start with, but stay tight.* Figs. 164 and 165 reproduce Figs. 29 and 30 of our brickwork specifications, and show clearly the construction of the gas baffles in the first and second tube banks. The wedge tiles over the mud drum are extra strong and made especially for the service. The remainder of the baffle is constructed of standard fire bricks and tiles laid in high temperature cement as noted in the figures. The wall marked 21 in Fig. 147 is supported on a heavy box-shaped girder R in Fig. 164 which is air-cooled as below described. The wall above this girder, marked 23 in Fig. 147 is not made of moulded bricks as used for horizontal boilers, as such bricks leak. It is built of fire bricks and cement *after the tubes are in place,* and can therefore be *made gas tight and remain so.* Or it may be made of plastic cement mixed and tamped into place between temporary wooden forms, and this form of construction is to be preferred.

There is no one method of baffling a boiler which is best for all fuels and methods of burning them. It is therefore necessary to adapt the baffling to the conditions to be met, and the Company reserves the right to make such changes of details as appear best when each installation is taken up.

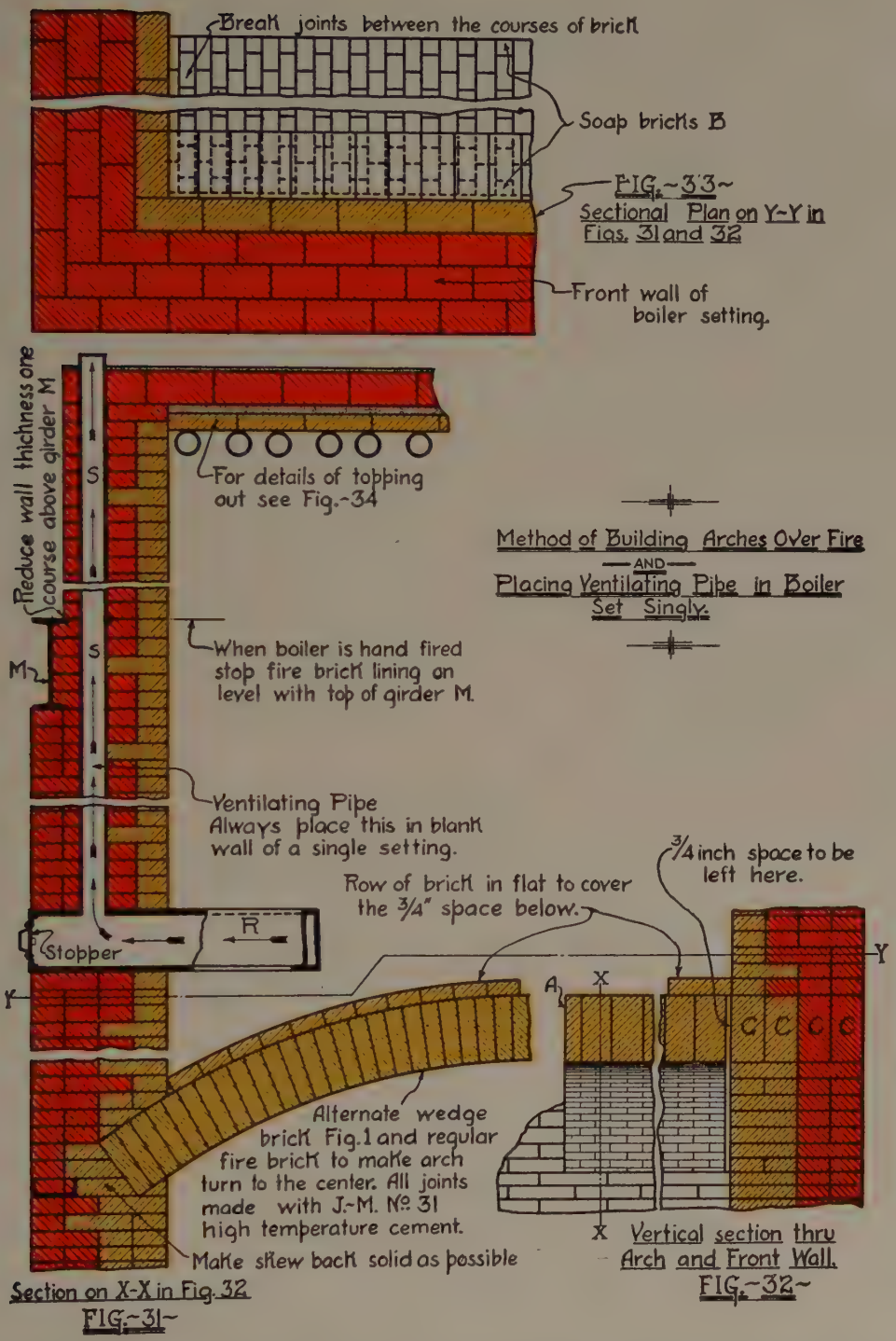
425. The Area of the Gas Passes has been carefully fixed, in the standard designs, to conform as nearly as possible to the relative volume of the gas at different parts of its path. Thus, if the gas temperature at the breeching is 500 deg. F. its absolute temperature is 960 deg., and if the furnace temperature is 2500 deg. F. its absolute temperature is 2960 deg. As the volumes vary as the absolute temperature it is evident that the volume at the damper will be only about one-third what it is the furnace, and the intermediate baffle openings should approximate the volume at such opening. This is seldom real-


Water level, center of rear drum, unless otherwise marked on blue print.
Make this wall 4½" or 9" thick as shown on print of the particular job, and build of No. 2 fire brick laid in No. 26, J.-M. cement or, preferably, make this wall of plastic cement tamped into place between forms made of wooden strips.
Boiler Tubes
Boiler Tubes
NOTE
Absolutely every joint between the tiles must be cemented gas tight with No. 31 J.-M. cement. Do not use any broken or warped tiles, or those with large corners broken off. TIGHTNESS is absolutely essential.
Build this wall with No. 2 fire brick laid in No. 26 J.-M. cement.
Cement finish J.-M. No. 26
Do not cement this joint. Place a strip of asbestos paper or felt here, so joint can slide
Ventilated Girder
Metal Strip
Leave ½" clearance here
Fire bricks laid flat
Fire bricks on edge
Bricks on end.
W
For size of this tile consult blue print of the particular job you are working on.
This joint sealed with No. 31 J.-M. Cement
M
Wedge like Fig. 6
12" x 12" x 2" Tiles
Boiler Tubes
According to the way the tiles work out, this projection may vary from 0 to 3 inches but should not exceed 3 inches the less the better.
Make bottom joint tight with No. 31 J.-M. cement.
MUD DRUM.
Standard shape fire brick laid flat.
Cement this joint.
Tile
Tubes
Side Wall
Section thru X-X, Fig. 29

Method of Placing Baffle Tiles Over First Tube Bank.
FIG. ~29~

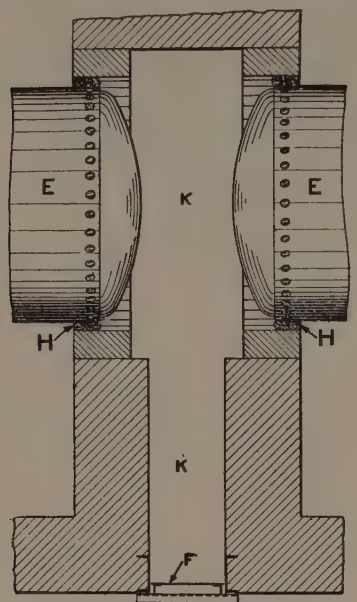
Method of Finishing Baffle Next to Side Wall
FIG. ~30~

FIGS. 164 AND 165, WHICH DUPLICATE FIGS. 29 AND 30 OF OUR BOILER SETTING SPECIFICATIONS, AND SHOW SOME GAS BAFFLE DETAILS. RED INDICATES COMMON BRICK. YELLOW INDICATES FIRE BRICK


Break joints between the courses of brick
Soap bricks B
FIG.-33-
Sectional Plan on Y-Y in Figs. 31 and 32
Front wall of boiler setting.
Reduce wall thichness one course above girder M
S
For details of topping out see Fig.-34
Method of Building Arches Over Fire
AND
Placing Ventilating Pipe in Boiler Set Singly.
M
When boiler is hand fired stop fire brick lining on level with top of girder M.
Ventilating Pipe
Always place this in blank wall of a single setting.
3/4 inch space to be left here.
Row of brick in flat to cover the 3/4" space below.
Stopper
R
Y
A
X
C
Alternate wedge brick Fig.1 and regular fire brick to make arch turn to the center. All joints made with J.-M. No. 31 high temperature cement.
Make skew back solid as possible
Section on X-X in Fig. 32
FIG.-31-
X Vertical section thru Arch and Front Wall.
FIG.-32-

FIGS. 166, 167 AND 168, WHICH DUPLICATE FIGS. 31, 32 AND 33 OF OUR BOILER SETTING SPECIFICATIONS, AND SHOW DETAILS OF WALL AND ARCH CONSTRUCTION, AND VENTILATION OF GIRDER SUPPORTING BAFFLE WALL. RED INDICATES COMMON BRICK. YELLOW INDICATES FIRE BRICK

ized, so it is common to find that the largest gas area is placed where the smallest volume exists, and vice-versa; thus note in Fig. 102 that the area between furnace arch and first baffle



PLAN ON A–A

FIG. 169

167 and 168 which are copies of Figs. 31, 32, and 33 of our brickwork specifications. Here the girder is marked R, and one end is open, while the other is closed by a stopper. Tube S duplicates exactly the action of a chimney and the girder is cooled by the strong draft of air through it. *Already this feature is being copied from us by other makers!*

427. The Baffle in Third Pass, marked 24 and 25 in Fig. 149, consists of firebrick tiles supported on T or angle irons as shown. This baffle is simply a gas deflector and is so made that the tiles may be lifted up and passed out through the side doors if desirable when repairs or inspection are necessary.

428. The Rear Baffle 26, Fig. 149, is made of steel or tiles, according to the requirements, but when tiles are used the top section is of metal which not only fits snug against the drum, but is provided with a slot containing asbestos rope packing so that the joint is absolutely gas tight. Every previous construction we have seen invariably leaks at this point, and when feather-edged tiles are used these soon crack so that the gas leaks become excessive, with corresponding reduction in boiler efficiency. The method we use is covered by a patent application now pending.

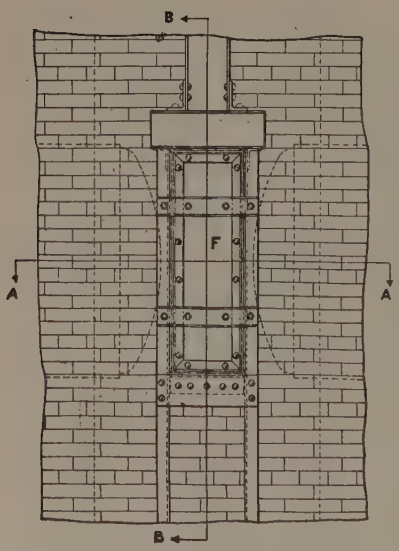
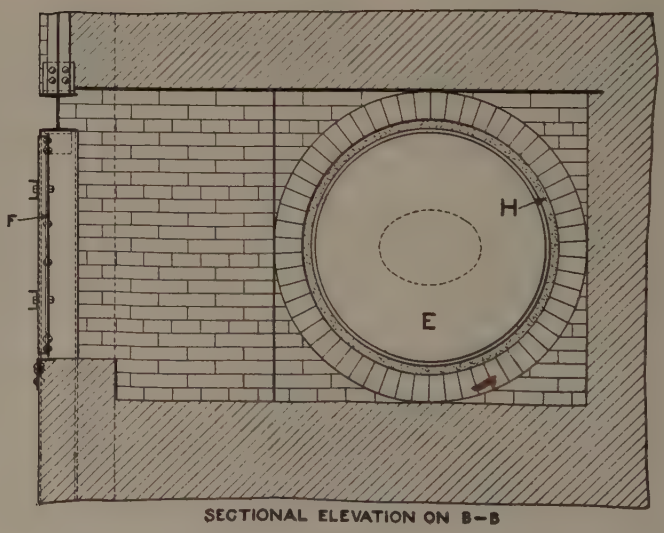


FIG. 170



SECTIONAL ELEVATION ON B–B

FIG. 171

SHOWING METHOD OF PROVIDING ACCESS TO THE BLANK HEADS OF MUD DRUMS OF TWO BOILERS SET IN A BATTERY

is considerably less than that in the rear gas pass, which is not good designing.

426. Air-Cooling of Girder marked 22 in Fig. 147 is accomplished as shown in Figs. 166,

429. The Arches Over the Fire, when such are used, are constructed as shown in Figs. 166 to 168 so that further description is unnecessary. The method of topping out the setting above the

drying tubes 9 in Fig. 149 is also shown, as well as details of bonding the walls.

430. Access to Blank Drum Heads for Inspection. A serious defect in the usual arrangement of cross drum boilers is that the blank heads of the drums are built into the brickwork, hence cannot be inspected. Corrosion of such heads often occurs, but as it cannot be seen it goes on unsuspected until an explosion occurs. That such is common is attested by casualty records. Read *The Mobile Boiler Explosion* in *Power*, March 25, 1919; also see photograph of one head of a boiler which exploded at Marion, Ohio, in *Power*, April 25, 1919, p. 582.

431. Boiler Insurance Companies therefore are looking askance at such construction and before long they will forbid it. This was realized when designing the Kidwell boiler, and means for getting access to the blank drum heads are provided. Advantage was taken of the opportunity to overcome another troublesome defect; namely, *the prevalent custom of making the party walls in batteries too thin*, so that they are neither durable, nor do they sufficiently prevent heat from flowing through them when one boiler is under fire and the other is shut down.

432. Our practise is shown in Figs. 169 to 171. E, E are two mud drums of a battery, and the party wall is 36 inches thick instead of 24 inches as usual. While this requires more bricks the trivial extra initial expense is more than saved in a short time because of the greater durability of the thicker wall which defers the need of repairs for a long time, and the flow of heat through the wall is greatly reduced.

This increased wall thickness makes it possible to provide the space K in Fig. 169 which permits access to the drum heads for inspection. This space is closed by the air tight door F. A similar door and opening are provided between the ends of the suspended water drum 2 in Fig. 147 and this door is marked 48 in Fig. 148. This feature of the design has received the highest commendation from Boiler Inspection and Insurance Companies. Already other makers are copying us as to this detail, thus admitting the superiority of our design.

Another material advantage of the increased wall thickness is that it permits ample provision for ventilating the portion of the boiler framework enclosed in this wall. A duct permits air to flow from the rear of setting to the bottom of the columns, thence around the columns up to the girders supporting the drums, thence between these girders to the rear of the setting. Details are fully given in our drawing and specifications for boiler settings.

433. Packing the Mud Drum Ends against air leakage has always been a difficult problem, and the means previously used have been unsatisfactory. The projection of the rivet heads required a clearance between drum and the ring of bricks surrounding it of such width that the packing soon works loose and permits leaks. This we have overcome by the method shown in Fig. 172, which is patented. On the inside of the wall a special slotted brick A is used for the inside ring around the drum, and this slot

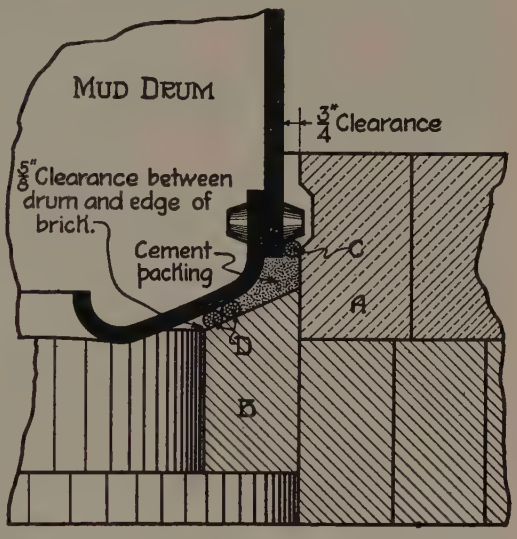


FIG. 172. METHOD OF PACKING MUD DRUM ENDS. PATENTED

is placed opposite the rivets. A tapered or splayed red brick B is used for the outside ring. Asbestos rope packing C is then inserted between the rivet and edge of the slot and caulked into place, and the arrangement *so locks this that it cannot work loose.* Fibrous asbestos packing is then placed between drum and the bricks, and finally the packing is completed by inserting two outside rings of asbestos rope D. Thus the packing is securely held into place so that the joint remains tight.

434. The suspended water drum 2, Fig. 147, is packed in the same way.

435. Access Doors in the Setting are provided in the front, side, and rear to afford entrance to the setting, permit blowing tubes by hand, etc. These are asbestos packed and air

tight. Sufficient of these doors are of the explosion type, to open automatically, release the pressure, and protect the brickwork if a gas explosion occurs. Enough doors are provided to permit access to all parts when desired.

436. In addition to providing the necessary access doors, the interior of the setting is so arranged that *a man can get inside and reach any point necessary when repairs or adjustments are needed!* In most cases the doors open into a nest of tubes or into places too small for access. This is important when superheaters are installed. See Sect. 523, and compare the accessibility of our design on the interior with Figs. 101, 102 and 120.

ticularly if a stack rests upon it, since the weight usually cracks the bricks and as the stack is swayed by the wind the bricks work loose and often shatter, thus intensifying the leakage. See Sect. 705 for particulars.

This is avoided in the Kidwell boiler. Fig. 173 shows the arrangement when the damper box is placed on top of the setting. The box is built of heavy channels securely cross braced, and forms an integral part of the boiler framework, so that it is put into place by the boiler erector instead of by the brick mason as usually done. On the top flange of channel D is riveted an angle A which forms a recess into which rests an angle B on the base of the stack or breeching,

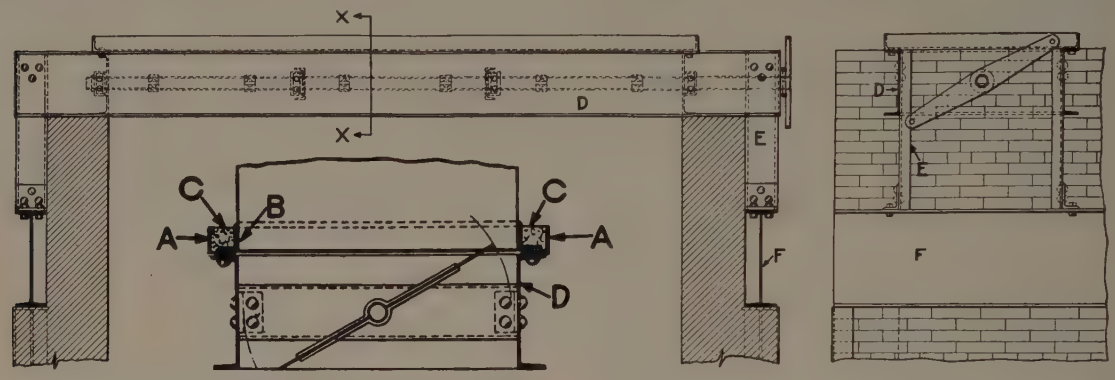


FIG. 173. SHOWING DAMPER BOX WHEN PLACED ON TOP OF BOILER SETTING

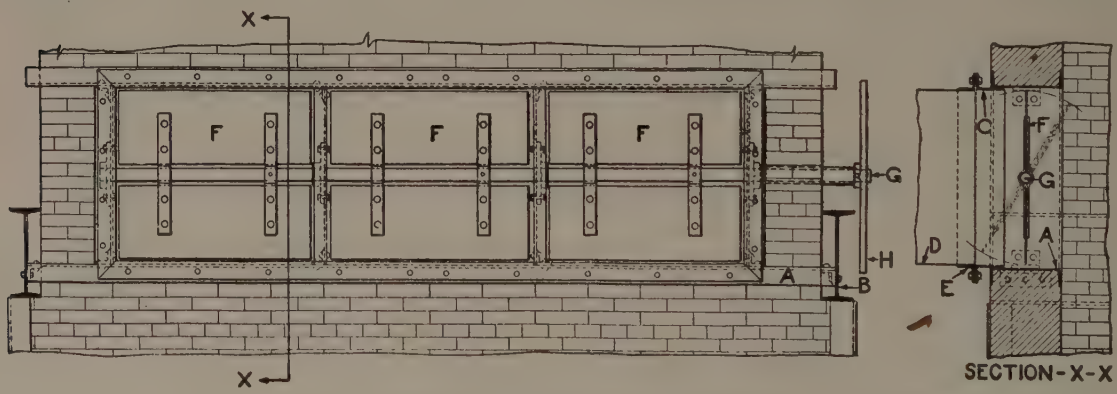


FIG. 174. SHOWING DAMPER BOX WHEN PLACED IN REAR WALL OF SETTING

437. The Damper Box or Frame is a detail requiring more attention than it usually receives. The common plan of supplying a light frame, with a projection over which the stack or breeching slips like a stove pipe, permits large air leakage hence is to be condemned. When such plate rests upon and has to be supported by the brickwork, it is still further objectionable, par-

and between A and B is a *sand seal* C which prevents air leaks. Columns E secured to girder F tie the box to the main frame.

438. When the damper is to be placed in the rear wall the arrangement is shown in Fig. 174. Here an angle C is riveted to the channel A forming the sides of the box, and the outer flange of this angle is punched with bolt holes ready

for connecting the angle E which forms the terminus of breeching D, thus providing for an air tight joint. The other details are apparent.

439. The Damper Is Balanced on its spindle and provided with operating arm as shown; all dampers are so made that when closed there is still an air opening of 12% to 15% of the full area, as required by Insurance Companies, to prevent accumulation of gas in the setting if fires are banked and distillation of fuel occurs. Unless such gas escapes it may cause an explosion and endanger the structure.

440. The Damper Area is always sufficient for operating at high ratings. Many boilers now installed with damper boxes only 12 to 16 inches wide severely throttle the gas, hence high ratings are impossible. In the Kidwell boiler the *least width* of damper box used is 22 inches, and for large units it is 30 to 36 inches.

441. The Furnace Details have been worked out with utmost care. The first step in developing each section was to fix the furnace volume, and then arrange the boiler to suit it. A general deficiency of previous designs has been inadequate furnace volume. It is now known that for good results such volume should be not less than as given in Sects. 162 to 170, especially if high ratings are to be obtained. All this has been provided for, as a comparison with other boilers will show.

442. Further, adequate distance from the fuel bed to the tubes must be provided to prevent dense smoke and escape of unburned volatile matter, and this item has likewise been fully considered. As it is impossible to reconcile these essential requirements with low settings, this Company does not offer boilers of a height insufficient to permit the installation of furnaces of the necessary volume and height. See Sect. 541(a) and 157 for further information, and for an illustration of the tremendous influence of furnace volume on fuel efficiency.

When oil fuel is used, not only must there be unusually large furnace volume, but the oil must be so fed that the atomized mixture is projected into a furnace of *expanding volume*. This requirement is perfectly met by the Kidwell boiler, as shown in Fig. 192.

443. The furnace can be adapted to any kind of fuel, whether solid, liquid, or gaseous or method of firing it, whether by hand, stoker, oil atomizer, gas burner, etc. For fuels requiring Dutch ovens or other forms of extension furnaces, such can be provided and of ample height to reduce the overheating or crucible effect inevitable when such furnaces are deficient in volume.

444. The furnace arrangement and the tube location have been so coördinated as to cause the maximum possible proportion of heat to be absorbed by direct radiation, which increases both the capacity and efficiency as shown in Sect. 175.

445. Openings for Pyrometer Measurements, taking draft readings or gas samples, are provided at sundry places throughout the setting, and are marked 47 in Fig. 149.

446. Summary as to Constructive Details. It follows that in the design of the Kidwell Two-Flow Ring-Circuit Boiler there is *not one* detail of construction that is new or untried, but that on the contrary every detail has been tested and proved correct by decades of experience. The improvements by reason of which this design excels others are due to eliminating from it every constructive detail which has proved even questionable in former designs, and then so assembling the proved details that the final combination produces results previously unobtainable, as will later appear. As to material, workmanship, perfecting of details, quality of appurtenances used, etc., the preceding description shows that this design stands in the very first rank and is excelled by none.

Operation of the Kidwell Two-Flow Ring-Circuit Boiler.

447. The Gas Passes are proportioned as stated in Sect. 425, and from fuel bed to damper the gases flow as shown by arrows in Fig. 147. They thus sweep the heating surface very efficiently, and avoid the short circuiting of gas which occurs in some designs. Considerable heat is imparted to the tubes by direct radiation in conformity with Sect. 175 and the remainder is imparted by conduction and convection.

448. Course of the Water. The feed enters the rear top drum as it should according to Sect. 67, flows down the rear tube bank, thence into mud drum, thence through the first and second tube banks until it returns to the starting point where the steam is disengaged. This water circuit is the mechanical equivalent of Gurney's ring, Sect. 346, and its design is fully explained in Sect. 462.

449. Relative Heat Absorbing Capacity of the Tube Banks. According to the method of firing the Kidwell boiler, and whether or not

superheaters are installed, and the degree of superheat to be produced, the percentage of the total heating surface contained in the three tube banks varies somewhat. On the average, starting from the mud drum the first, second and third tube banks will contain respectively 35%, 30% and 35% of the heating surface, and these proportions will be assumed in the following analysis.

The first step necessary for a proper discussion of what goes on inside of the boiler is to determine what proportion of the total heat imparted to it by conduction and convection is absorbed by each of these tube banks. This will vary somewhat with the kind of fuel, amount of it burned, and the furnace temperatures, but such variation will not appreciably affect the following deductions.

450. Heat Transmission Curves. Fig. 175 shows certain curves from which we can determine the heat imparted by conduction and convection. Curve C differs from the others below described in that it represents the amount of *steam generated,* and is plotted from tests on the Niclausse boiler, Sect. 245. Curves A and "a" are plotted from a formula deduced by Mr. John E. Bell and given in Transactions A. S. M. E., Vol. 29, p. 267. Curve A shows the relation between the amount of heating surface passed over and the *total heat absorbed* from the start up to any point on the scale, and curve "a" shows the corresponding gas temperature at each point, assuming a furnace temperature of 2500 deg. and a breeching temperature of 500 deg. Curves B and "b" give similar information on the assumption that the gas starts with a temperature of 3536 deg. and leaves at 527 deg., which covers a range not likely to be exceeded by any stoker or oil firing. These two curves are plotted from computations by Breckenridge given on p. 356 of Bulletin 23, Bureau of Mines, *Steaming Test of Coals.*

451. From curve A the first, second and third tube banks absorb respectively 73%, 19% and 8% of the heat, while from curve B these amounts are 67.39%, 22.32% and 10.29%, and the averages from the two curves are 70.2%, 22.66% and 9.14%, all referring of course to the heat imparted by conduction and convection only. If for instance the furnace is so arranged that 20% of the total heat generated in it is imparted to the boiler by direct radiation, then the above percentages refer to the remaining 80%, so that the tube banks will then absorb by conduction and convection alone, 56.16%, 16.53% and 7.31% of the total heat generated, and adding to the 56.16% for the first bank the additional 20% absorbed by radiation, that bank will then absorb 76.16% of the total heat.

The percentage of the radiant heat compared with the total amount generated varies greatly with the furnace arrangement, but the greater the percentage of heat imparted by radiation the better the action of the boiler is (see Sect. 175), and the more forcibly the following deductions will hold. We will therefore assume the most unfavorable conditions and ignore radiant heat in the following investigation.

452. Suppose that the boiler is operating at 150 lbs. gauge pressure, and receiving feed at precisely the same rate at which steam is being generated and that such feed water is heated to 200 deg. The steam temperature is 338 deg. and the total heat of a pound of steam above 200 deg. is 1026 B. T. U., and the heat necessary to raise each pound of entering feed to steam temperature is 138 B. T. U. The first point to determine is whether in its passage from the feed entrance, down the rear tube bank, and into top of the mud drum this water will be brought up to the boiling point.

453. Since each pound of it requires 1026 B. T. U. for its conversion into steam, then as above shown, an average of 9.14% of this will be absorbed in the rear tube bank, that is, $1026 \times 0.0914 = 93.78$, or in round numbers, 94 B. T. U. But, this is 44 B. T. U. short of the amount necessary to bring this water up to steam temperature, *hence boiling will not occur in that tube bank.* Therefore, this water will have to pass some distance up the first tube bank before it begins to boil, and the colder it is when fed into the boiler the more so this fact is true, exemplifying Rice's statement in Sect. 355 that:—"A boiler can have its output reduced almost to zero in a small fraction of time by the introduction of *cold feed water.*"

454. If the feed is stopped and all of the water in the boiler has made a complete circuit then there is no entering feed to be heated, hence at first glance it would appear that the heat absorbed in the rear bank would then generate steam in that bank. That does actually happen in some designs, but not in the Kidwell boiler. To show this requires a much more complicated analysis than above given, and this will disclose several facts which greatly modify the preceding computation, but only to the extent of intensi-

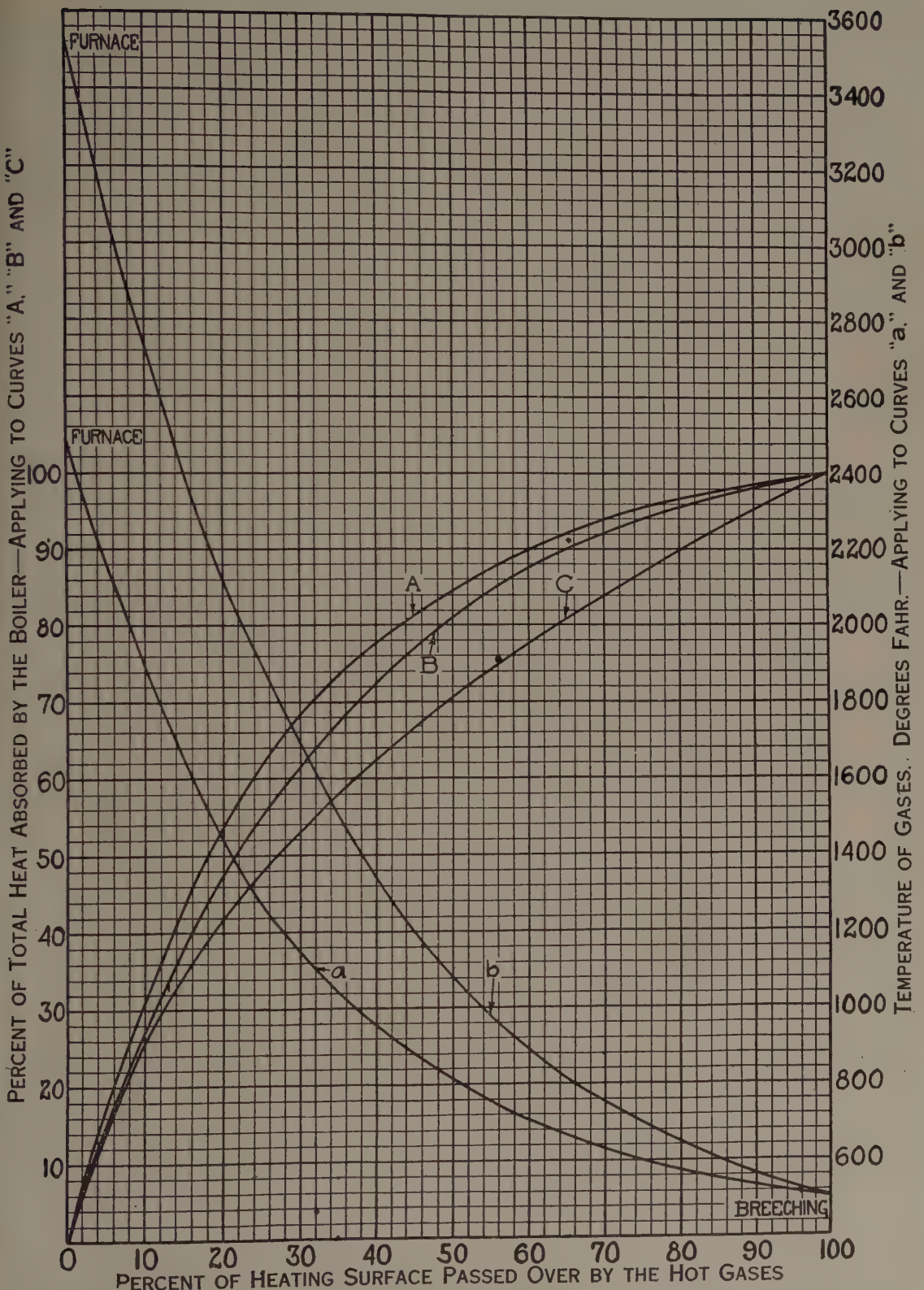

FURNACE
FURNACE
A
B
C
a
b
BREECHING
PERCENT OF TOTAL HEAT ABSORBED BY THE BOILER—APPLYING TO CURVES "A," "B" AND "C"
TEMPERATURE OF GASES. DEGREES FAHR.—APPLYING TO CURVES "a" AND "b"
PERCENT OF HEATING SURFACE PASSED OVER BY THE HOT GASES
0 10 20 30 40 50 60 70 80 90 100
10 20 30 40 50 60 70 80 90 100
600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600

FIG. 175. CURVES A AND B SHOW THE RELATION BETWEEN GAS TEMPERATURE, HEATING SURFACE, AND PERCENTAGE OF HEAT IMPARTED TO THE WATER BY CONVECTION AND CONDUCTION. CURVE C SHOWS STEAM GENERATED IN NICLAUSSE BOILER, FIG. 71

fying the conclusion therein reached. It was tacitly assumed above that the boiling point of the water is *everywhere the same* as the temperature of the steam leaving the boiler. This is not so except right at the top surface of the water. In Sects. 53 to 57 is shown how the boiling point varies with the depth of the water. This has an influence seldom previously realized.

large in comparison with the amount of feed water necessary just to replace the quantity of steam generated. The ratio between the two may equal 300 to 500 or more, so assume 300 as a low figure.

456. If the feed is stopped and the water in the boiler has made several circuits, it will when starting down the rear bank of tubes be already

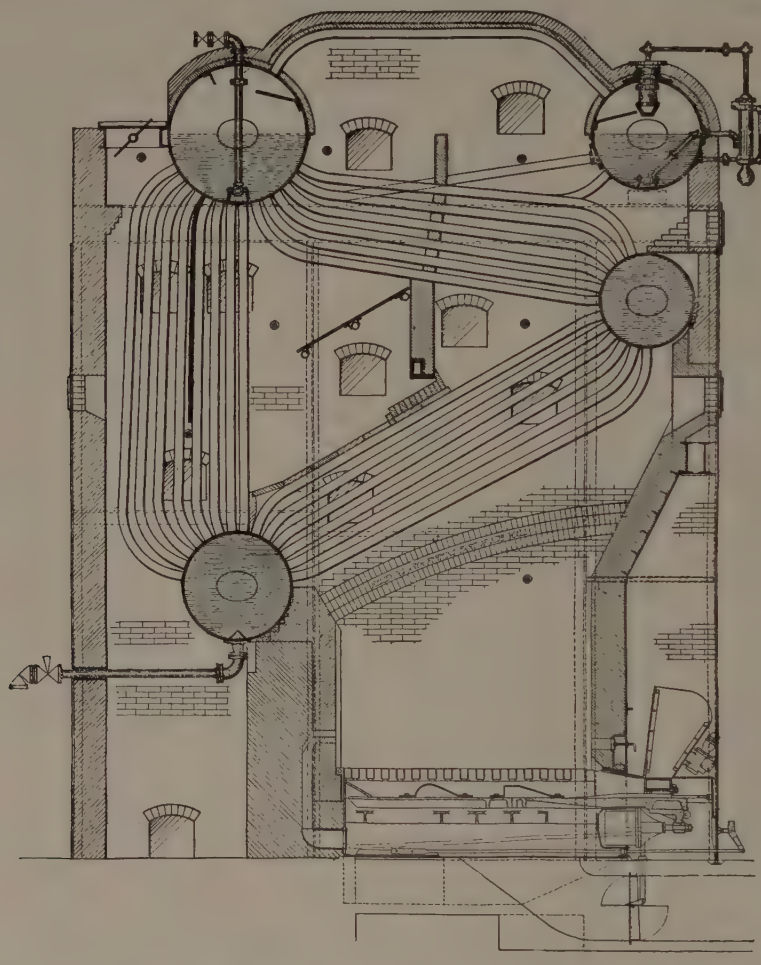


FIG. 176. KIDWELL BOILER AND TYPE E STOKER

455. In a boiler operating on the ring-circuit principle with unrestricted circulation the water speed is many times greater than possible in designs with throttled circulation. In later editions of this book the matter of water speed will be treated more fully. Suffice it to say here that in a design like the Kidwell boiler an average speed of 5, 6, 8 or more feet per second is possible according to the rating at which the boiler is driven. In consequence, the amount of water passing any point in the circuit is extremely

at the steam temperature, or boiling point at the water line. But as soon as it descends it passes into a region of greater pressure and increased boiling point, hence it cannot continue to remain at the boiling point at every stage of its journey toward the mud drum unless *sufficient heat is added, all along its path,* to bring it up to the boiling temperature corresponding to the increased pressure at every point in its travel. While in Fig. 7 the water at the bottom has to be 7 deg. hotter than at the top if

boiling is to occur, the difference in any other case will vary with both the depth of the vessel, and the steam pressure under which it is operating, so assume the slight difference of 3 deg., which is less than would exist in any but a small boiler operating at extremely high pressure.

457. Then, instead of having to heat one pound of feed water 138 deg. as in Sect. 453, we in this case will have to heat 300 lbs. 3 deg., which will require 900 B. T. U. But, as in the preceding case we have only about 94 B. T. U. available for doing this heating, since only that amount is absorbed in the rear bank, hence said water will not be at the boiling point when it reaches the mud drum and turns upward into the first bank of tubes, *therefore actual generation of steam will not begin until this water passes far enough along that bank to absorb from the furnace sufficient heat to bring it to the boiling point.* In any actual case it is possible in this way to compute approximately just where steam generation begins in the first bank of boiler tubes.

458. If feed is now admitted as in Sect. 452 we can recompute that case much more exactly, as follows. The feed water and water already in the circuit mix intimately (Sect. 413) and in order to bring this mixture to the boiling point by the time it reaches the mud drum the heat needed will be

For 1 lb. of feed at 200 deg.	138 B. T. U.
Boiler water, 300 lbs. raised 3 deg.	900 B. T. U.
Total.....	1038 B. T. U.

For doing this we have available only 94 B. T. U., hence the water cannot be raised to

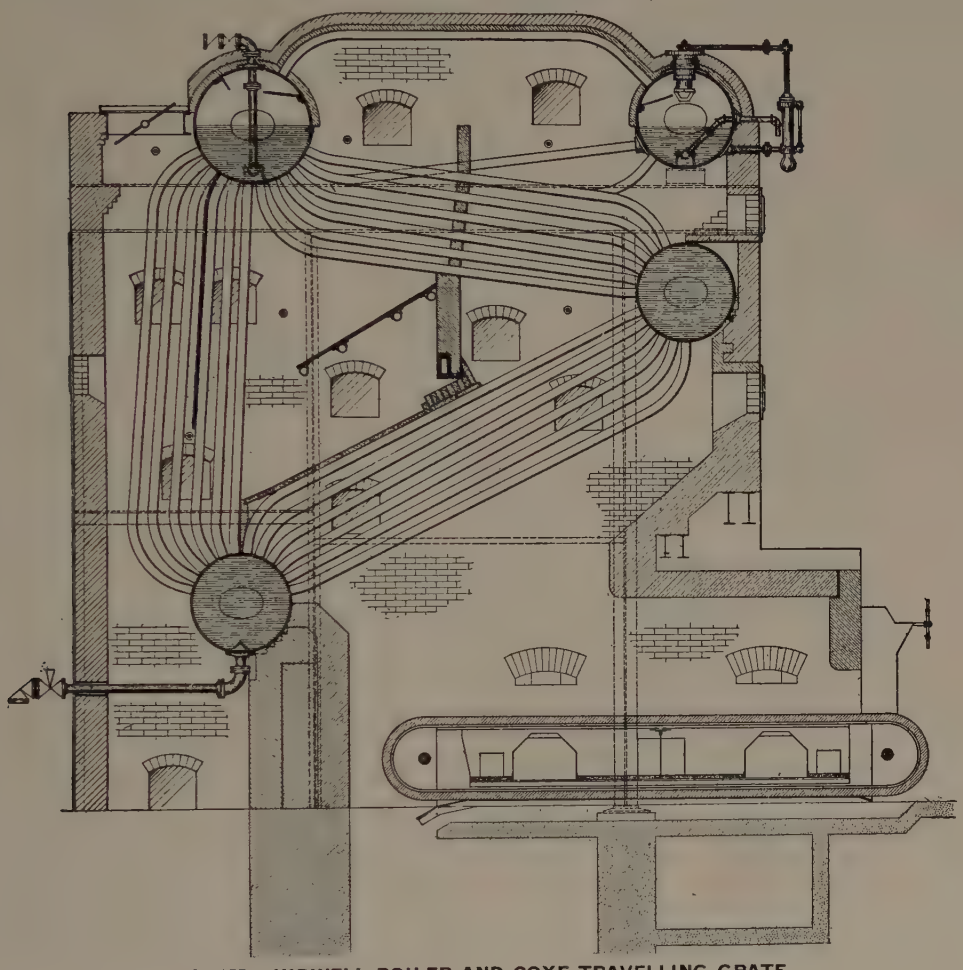


FIG. 177. KIDWELL BOILER AND COXE TRAVELLING GRATE

the boiling point by the time it reaches the mud drum. Further, the total heat imparted to the boiler for generating a pound of steam in this case is only 1026 B. T. U., *or less than the total above shown,* so that at first sight it would appear that the water could not even be brought up to the boiling point, much less produce any steam! The solution of this seeming paradox is contained in Sect. 57(c). The heat absorbed in the down-flow is given up again in the up-flow,

459. It is apparent that the greater the number of restrictions in the circuit, the slower the water can travel, hence the less the quantity flowing will be, therefore the higher the temperature produced in it with a given quantity of heat. This produces three evils! (a) Assuming any given feed temperature to start with, the less the rise of temperature is in the down-comer the greater the temperature difference between the water inside and gas outside, hence

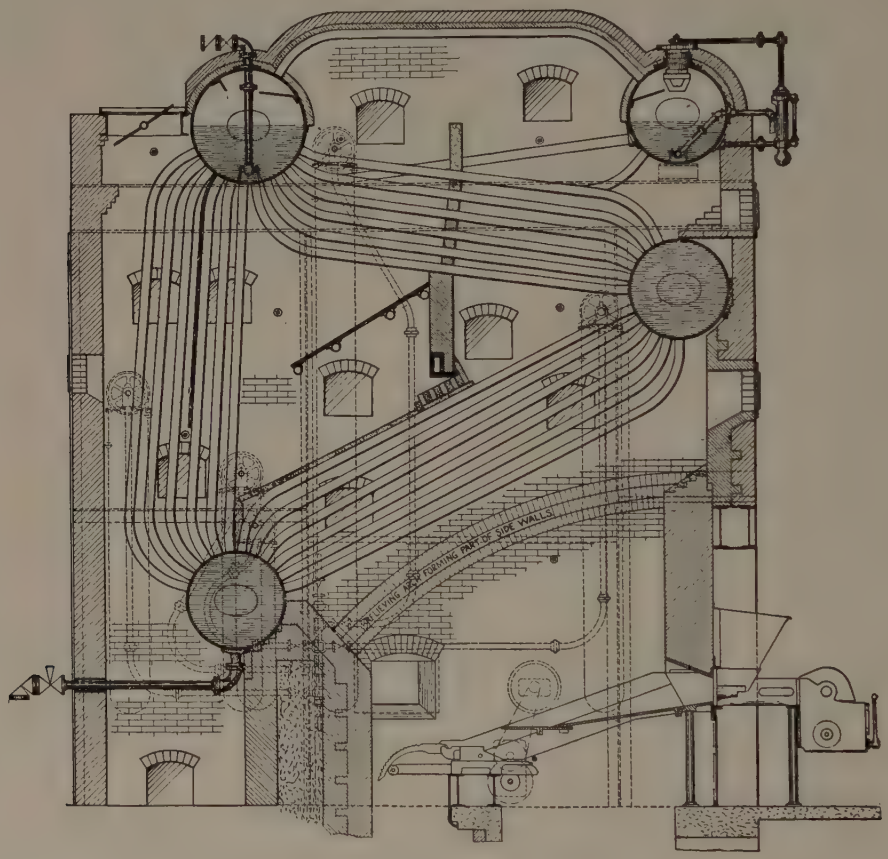


FIG. 178. KIDWELL BOILER, RILEY STOKER, AND VULCAN SOOT BLOWER

and during the up-flow the *temperature of the water decreases,* hence when the water in the above case reaches a height at which the heat is absorbed in the down-comer, plus that absorbed from the furnace, brings it to the boiling point, then *steaming begins.* And from this initial steaming point up to the water line above, its temperature is regularly decreasing, and it is simultaneously yielding up stored heat which in combination with the additional heat absorbed from the gases, produces steam.

the more efficient the heat absorption. To make this clear consider the following analogy. Apply a torch to the rim of a fly wheel. If the wheel is stationary you can quickly heat a spot and melt it, but if the wheel is rapidly revolving you can barely heat the mass of metal more than a few degrees, even though the amount of heat absorbed is greater than before. It is scattered through a greater mass of metal, and whisked away from the torch before there can be any considerable rise in temperature. Similarly, in

the boiler the greater the quantity of water passing the more heat taken up, even though the temperature rise in the water is trivial. (b) The nearer the water in the down-comer approaches to the boiling point, the greater the danger of reversal of circulation when the steam pressure suddenly drops and "pop-bottle" action occurs as explained in Sects. 85 to 87. (c) As already shown in Sects. 75, 76, 77, 249 to 253 and 257 to 266, the weakness of many boiler designs is steam locking of the tubes over the fire due to poor circulation. It is clear, then, that the action in the Kidwell boiler whereby *steam generation does not begin until the water moves up the front bank some distance from the mud drum*

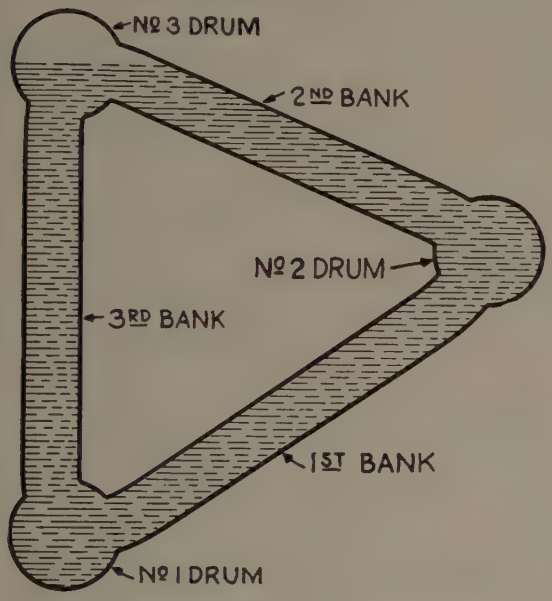


FIG. 179. WATER CIRCUIT OF KIDWELL BOILER

serves as an insurance against steam locking, and thus increases both the capacity and durability of this boiler! And in a more effective way we accomplish what Bancel seeks to do for horizontal water tube boilers when he says:—"The tendency for reversal of circulation is lessened by setting the boiler so that the gases strike the tube bank at its higher end."—*Circulation in Horizontal Water Tube Boilers,* A. S. M. E. Transactions, 1915, p. 1035.

460. From all of which it follows:—*That in Kidwell boilers no steam is generated in the rear tube bank, therefore all steam produced is generated in the first two banks, and this boiler will not reverse its circulation under any permissible conditions of operation.*

461. Proper Relation of Gas and Water Flow. The feed is entered at the proper point in accordance with Sect. 133. It is also thoroughly mixed with the water flowing in the circuit, so there can be no concentration of solids such as shown in Sect. 231. The relation of gas and water flow is very nearly that as specified in Sect. 132 for maximum fuel economy, because as the water flows from the mud drum into and through the first two tube banks its temperature is decreasing, after boiling starts, and the temperature of the gas sweeping these surfaces is likewise decreasing. Similarly, in the back pass of the rear bank the gases go upward and decrease in temperature, while the water descends and increases in temperature, hence the hotter gases envelope the surfaces containing the hotter water, which likewise complies with this requirement. The only part of the circuit in which

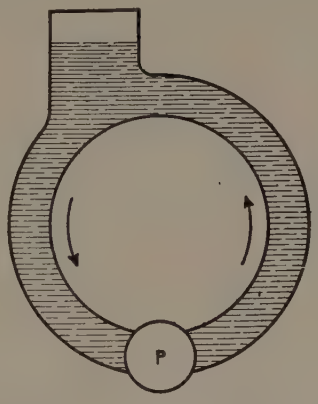


FIG. 180. ILLUSTRATING RING-FLOW CIRCULATION

this law is not complied with is in the first half of the rear tube bank where the gases become colder as they sweep along tubes in which the water is getting warmer, but this involves only about 17% of the heating surface, whose *total heat absorption* is only about 5% of the whole amount imparted by conduction and convection, hence the effect of such contrary flow of water and gas at this low temperature and small amount of surface is very little. Assume it made a difference of 2% of the total heat involved in that part of the flow; this would make a difference of only 0.1 of one per cent of the *total heat* absorbed, which is negligible. The proportion in other designs is usually far larger, for which see Sects. 232, 274, 290, 293, 294, etc.

462. The Water Circuit. Fig. 179 shows the form of the circuit where each bank contains the same number of tubes in depth, as in Figs.

178 and 192. This is the mechanical equivalent of Gurney's ring, Fig. 136, so far as confining and conducting the water are concerned. Better to appreciate its action refer to Fig. 180 in which, as in Figs. 9, 10 and 103, we install a centrifugal pump to vary the water speed at will. No matter how fast we operate this pump, the up-comer side delivers the water *right into the entrance of the down-comer,* therefore we eliminate the troublesome and pernicious difference of level between points A and B, Fig. 9, *always present when the up-comer and down-comer are some distance apart, as in every U-tube design!* The serious consequences of such difference of level are pointed out in Sects. 60, 61, and 296 to 299. The ring-shaped water circuit provides the only remedy for this evil, and as the pump in Fig. 180 operates, the water line above will not fluctuate severely with each change of pump speed, but the water in the system, if the ring is of uniform bore, will move evenly through the circuit like the belt around three pulleys shown in Fig. 181.

463. This perfect action can be spoiled by wrong proportioning of the ring, however. If the up-comer be constricted at the top it will produce a fountain effect as in Fig. 10, or a scattering spray, as in Fig. 76. The same thing will occur if the section is made like a bag pipe, as in Fig. 78B. Therefore, *to obtain a quiescent water surface the circuit must be of ample cross section, and the up-comer area from the pump in Fig. 180, or the mud drum in an actual boiler, must practically maintain its original area, but never sensibly decrease or throttle it.* This principle is carried out in the Kidwell boiler.

is, in the up-comer. But, as stated in Sects. 46 and 47 it is the freely rising steam which produces circulation, or water flow in a boiler, and that in consequence thereof, in a properly designed boiler the water speed in the circuit must be *greatest over the fire and in the up-comer conveying the steam from the tube surfaces as*

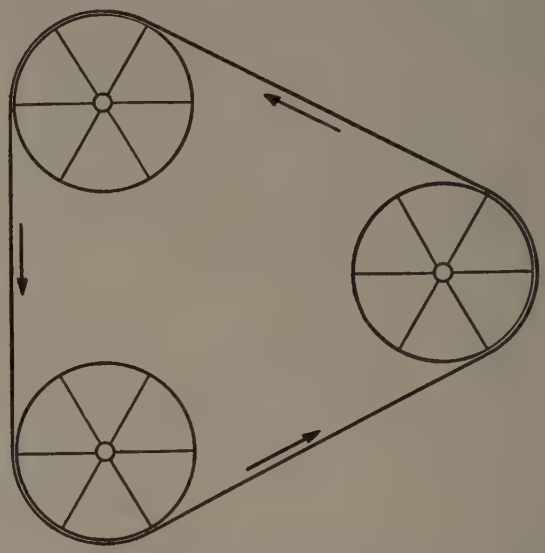


FIG. 181. MECHANICAL ANALOGUE OF WATER FLOW IN FIG. 179

fast as formed. In short, the more steam present the greater the speed should be. This vital requirement, unattainable in practically all previous designs, is perfectly met in the Kidwell boiler, as follows:

465. Area-Velocity Diagram. In this boiler some sections contain the same number of tubes

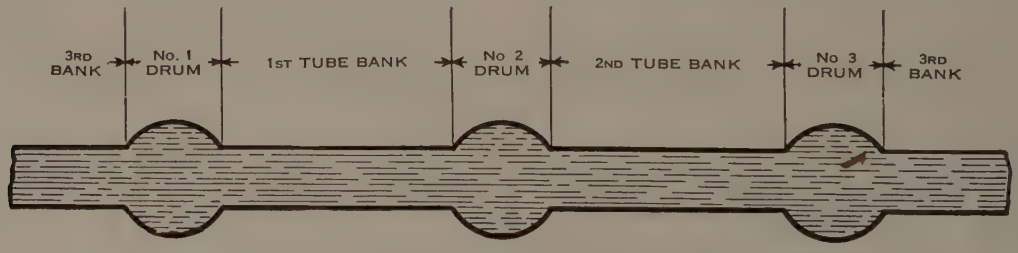


FIG. 182. AREA DIAGRAM LIKE FIG. 33 FOR KIDWELL BOILER WITH TUBES AS IN FIG. 178

464. Relative Water Speed in the Tube Banks. If only water flows through the circuit as in Fig. 179 the analogy of the belt in Fig. 181 is perfect. In a boiler, however, another element enters and *improves the action,* as follows. In Sects. 459 and 460 it is proved that *all the steam is generated in the front two tube banks,* that

in each bank, as in Fig. 178, otherwise the rear bank always contains more tubes than the front bank, as in Figs. 149 and 150. This tube arrangement is varied to suit the conditions of the particular case in hand. Lay out the water circuit of Fig. 179 on a base line precisely as done in Fig. 33, and neglecting the water space

in drum No. 3 the resulting figure will be like Fig. 182. Note that *the tube cross section is the smallest section in this circuit,* therefore since the water speed varies inversely as the area of the circuit, *the maximum water speed will be through the tubes, which is precisely as it should be!* If only water were flowing, the speed would be the same in all tube banks in this figure, but as above stated, another element enters, and *that is the steam itself!* As steam is generated gradually along the up-comer its volume greatly exceeds that of the water from which it was formed, hence the *volume of the emulsified steam and water continuously increases along the up-comer, therefore the velocity of flow increases in precisely the same ratio,* hence the requirements of Sect. 52 are met to the letter. Contrast this with any of the other designs dissected in this book.

470. The only way to prevent either such result from occurring is *to provide each tube with its own up-comer of the same cross section,* which the Kidwell boiler does, hence the steam thus has 100% opportunity to produce maximum circulation.

471. Contrast this with the header types, particularly those with nipples, and consider the comment of Hosea Webster in Sect. 249. Would any sane business man, much less an engineer, admit that the way to develop the maximum traffic capacity of a 6 to 27 track railway is to provide only one entrance and one exit track for

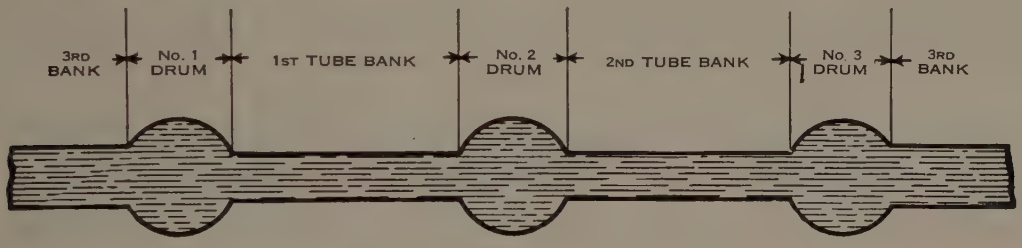


FIG. 183. AREA DIAGRAM FOR FIG. 147

466. If the front banks contain fewer tubes than the rear bank as in Figs. 149 and 150, the area diagram will be like Fig. 183 and the velocity diagram just the complement of this, and all the above applies as before. Therefore:—

467. *In the Kidwell boiler the maximum speed of flow is just where it should be, namely, over the furnace and in the up-comers,* as laid down in Sect. 52. That such flow cannot be reversed in direction is proved in Sects. 459 and 460.

468. The velocity of flow is further aided by the liberal angle of inclination of the tubes. A prominent maker of header types states:—"The inclination of the tubes is *one inch per foot,* and is *such as to produce rapid circulation toward the front header.*" Compare this with any cut of the Kidwell boiler shown in this book and the superiority of its design as to this item too self evident to need comment.

469. Subdivision of the Up-Comer. It is shown in Sect. 51 that to produce rapid circulation the steam and water must be fully emulsified. If the up-comer outlet is suddenly enlarged, as in some water leg designs, the effect is as shown in Fig. 78A. If it is severely contracted Fig. 37 shows what results, and Sects. 75 and 76, and curve D in Fig. 4 show the effect in reducing the fuel efficiency.

main terminals? Clearly not! Is there any sounder reason why 6 to 27 tubes can generate and deliver with safety the maximum quantity of steam when they have but *one entrance and one exit tube?* The same considerations apply, and in both cases the answer is NO, and will be until the laws of physics are changed. *If this erroneous idea of throttling tubes, which started as shown in Sect. 67, etc., were correct, then it would be easy to take advantage of it by inserting in every up-comer tube of the Kidwell boiler a plug containing a hole whose area is only from 16% to 4% of the tube bore!* This suggestion is not sarcasm. It has actually been carried out by Boyrie, Anderson and Solignac in Figs. 82B, 83, and 90. If it *will improve the water and steam flow then the same method should be applied to the smoke stack to accelerate the gas flow!* See the analogy in Sect. 579. The absurdity and casuistry* of the whole scheme is so apparent that we waste no further time on it, but leave it to the judgment of the reader. Inci-

*Owing to lack of space the foot note above referred to has been transferred to bottom of following page.

dentally, the following section also sheds some light on this question.

472. The Maximum Possible Water Flow Through a Boiler Tube. As the quantity of heat imparted to the up-comer increases, so does the amount of steam generated, hence if sufficient heat be imparted it is possible to evaporate *all of the water flowing into the tube* and thus deliver only steam at the top of the up-comer. If but little heat is imparted, but little steam is generated, hence only a small quantity of water flows. Between these two extremes there must be some condition under which the maximum possible quantity of water will pass. It can be proved mathematically that this condition obtains when the volume of steam in the up-comer equals the volume of water, that is, the contents of the up-comer consist half by volume of steam and half of water, *mixed in an emulsion.* The same thing is true of air, and this is graphically shown by Fig. 184 which is from Bancel's paper above quoted, and derived from experiments on air lifts. Note that the ordinate dropped from the point of maximum water flow in curve 1 intersects curve 2 directly opposite the reading 0.5 on the specific gravity scale, showing that the mixture is half of air and half of water, as measured by volume.

473. Note how rapidly the water flow increases up to the maximum and how slowly it decreases after the maximum. As applied to a boiler this means that, *if not prevented by a throttled circuit* the water flow increases very rapidly as the boiler rating increases, and since it is the water which sweeps away the steam bubbles and prevents the tube from overheating, it is a matter of supreme importance so as to design a boiler that the maximum speed of water flow is not reached except at an extremely high rating, and further, to arrange the circuit so that its resistance to flow is the least possible in order that *the quantity that flows at every rating will be the maximum possible to get through it at that rating!* And, as shown in Sects. 31 and 32, if the quantity passing is sufficient to water-sweep the tube surfaces (*i. e.*, prevent steam locking) the tube cannot become overheated.

474. Mr. Geo. H. Babcock in a lecture delivered at Cornell University and reported in *Steam,* p. 28, says that in a boiler of the general design of Fig. 30 this point of maximum flow is reached at 117% of rating, which at that time was based on 11½ sq. ft. per HP., which corresponds to 103% when rated on 10 sq. ft. as customary today. His computations do not appear to take into account the friction in the tubes, and the boiler he assumed as a basis of his computations was not very many tubes high, hence its resistance to water flow was far less than in boilers containing from 14 to 27 tubes high, as used today, like in Fig. 35. See Sect. 482 for maximum flow in the Kidwell boiler.

475. The Manner in which Heat is Imparted to Up-Comer Greatly Influences Capacity. This seems never to have been realized, hence deserves particular consideration as its consequences are far-reaching. The liability of a tube to burn by steam locking varies directly with the amount of steam traveling in that tube, and the temperature to which it is exposed, and inversely with the speed of the water through the tube.

476. Refer to Figs. 35, 86, etc., and note that all of the heat absorbed in the rear gas passes is swept forward into the pass over the fire, hence *the liability of such tubes to burn is precisely the same as if all the steam were generated in this pass,* as it often is. Now suppose the arrangement were so changed that the heat were applied at the lower end of the tubes, then the tubes over the fire would convey only the steam generated by the gas sweeping that pass, therefore the amount of steam in the tubes would be less than in the present arrangement, hence decrease the liability of overheating, and the efficiency of the boiler be increased for reasons given in Sect. 132. But because of other deficiency of design the liability of reversal of circulation would be increased, for which see Sect.

The following foot note applies to reference on preceding page:

*The tenacity with which many still cling to this effete argument is so inexplicable that we long sought for a parallel case, but in vain until the following was turned up from the days of long ago.

Joseph Addison, who flourished in London about the year 1700 essayed the role of dramatist and produced a play in which a rejected and broken hearted suitor sallied forth on the stage, assumed a woe-begone attitude with his hand over his heart, and declaimed in a lugubrious voice:—

"My wound is *great,* because it is *so small!*"

Several nights later an entering patron capped this by crying out

"Oh! It would be *greater* were it *none at all!*"

Illogical? Not more so than such nonsense claiming that nipples and similar throttling devices give "ample provision for efficient circulation."

235 (b) and Par. 48 of Bancel's paper as cited in Sect. 249.

477. Next refer to Figs. 102 and 143, and note that the middle and rear banks are both down-comers, hence all heat absorbed by them, and any steam generated in them, must be swept into the front bank, hence *the final effect is precisely the same as if all steam produced by the boiler were generated in the bank of tubes directly over the fire.*

478. From Sect. 451 note the proportion of heat absorbed by the respective tube banks of the Kidwell boiler. If it be assumed that 20% of the total heat absorbed is imparted by direct radiation then it can be proved that the total heat absorbed by the bank over the fire, plus the heat swept in from the rear bank, cannot in any event generate over 79% of the total steam produced by the boiler, hence the other 21% is generated in the second bank *away from the fire and not subjected to furnace temperature or danger of burning so long as there is any water whatever in the tube!* If less heat is imparted by radiation than asumed, then a still larger proportion of the steam will be generated in the second tube bank.

479. Therefore, if a boiler like Fig. 102 and a Kidwell boiler of identical heating surface are operating at identical ratings, the tubes over the fire in the former will be conveying 100 lbs. of steam while those in the latter are conveying only 79 lbs., so that if the *water speed in the two cases were identical,* the chances of a tube burning in Fig. 102 as compared to the Kidwell boiler will be 100 to 79. This means that the relative security of the Kidwell boiler is 26.6% the greater, *if the water speed is the same.* But it is not. In the Kidwell boiler the freedom of the water circuit from the restriction pointed out in Sect. 298 and Fig. 103 causes its speed of circulation to be about 4 times faster than possible in Fig. 102. Consequently, if Fig. 102 can develop with safety any given maximum rating, the Kidwell boiler can with equal security develop $4 \times 126.6 = 506.4\%$ of that same rating.

480. If there is a reversal of flow, or back-boiling in the front bank of Fig. 102 as some maintain there must be because of the throttling in the water circulation above, all heat absorbed in the down-flow will pass into the front tubes and make the matter just that much worse, which has been proved in cases where baffles

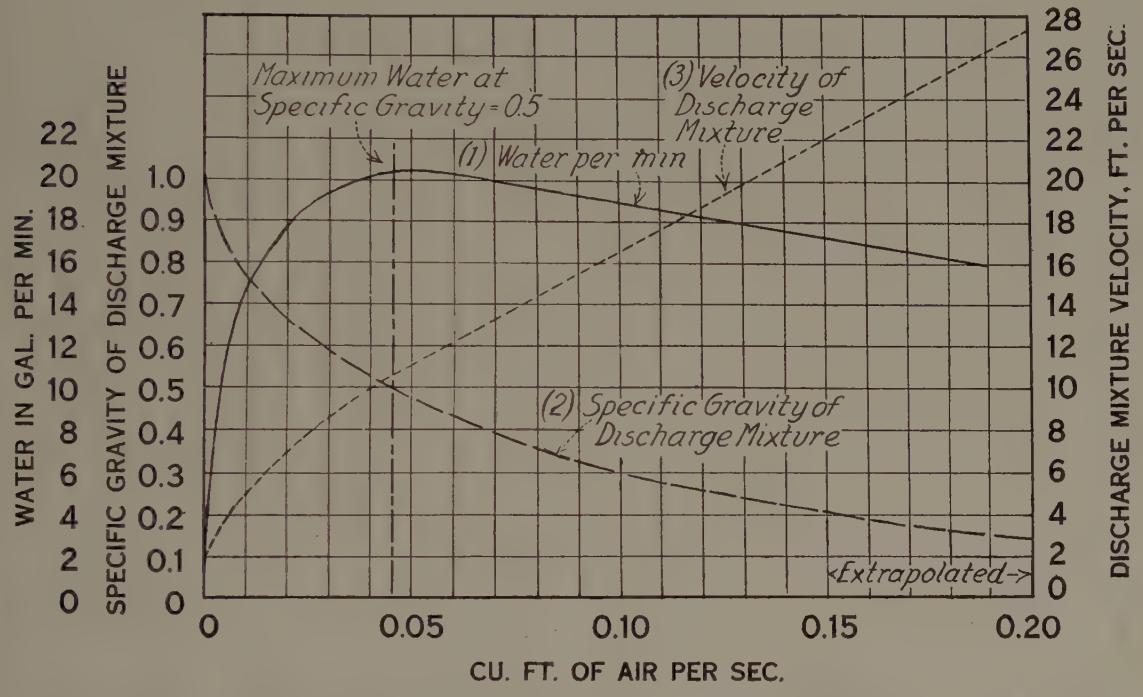

Maximum Water at Specific Gravity = 0.5
(3) Velocity of Discharge Mixture
(1) Water per min
(2) Specific Gravity of Discharge Mixture
<Extrapolated->
WATER IN GAL. PER MIN.
SPECIFIC GRAVITY OF DISCHARGE MIXTURE
DISCHARGE MIXTURE VELOCITY, FT. PER SEC.
CU. FT. OF AIR PER SEC.
0
0.05
0.10
0.15
0.20
0 2 4 6 8 10 12 14 16 18 20 22
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28

FIG. 184. GRAPHICAL PROOF THAT MAXIMUM QUANTITY OF WATER FLOWS WHEN STEAM AND WATER IN UP-COMER ARE EQUAL IN VOLUME

have been inserted in this front bank. See Sects. 316 and 317.

481. As it is a proved fact that Fig. 102 can, *so far as burning of tubes is concerned,* be operated with safety at overloads impossible of attainment with header types, the additional capacity of the Kidwell boiler over such types is clear. Therefore:—

By reason of correct design of its steam generating portion the Kidwell boiler can with equal security operate at ratings several times greater than possible in types like Fig. 102 for which free circulation has been claimed, and at proportionately higher ratings than possible in any header design.

482. Maximum Possible Safe Ratings. In a circuit of the shape of Fig. 179 it can be shown that, even taking into account friction in the tubes, the point of maximum water flow is not reached until the boiler is operated at about 374% of rating. This is 263% *higher* than Mr. Babcock claims for his boiler in Sect. 474. Therefore, on this showing it is just as safe to operate a Kidwell boiler at 363% of rating as to operate the boiler Mr. Babcock described, at rating, and if the friction in the circuit be considered the ratio will be found still greater, and nearer that shown in the last part of Sect. 479. Therefore, if header types can operate at such ratings as claimed in Sect. 249, a Kidwell boiler can operate at ratings many times greater. See Sect. 256 for further particulars.

483. When insistent claims are made that header types can be operated at such high ratings as are stated in Sect. 249, it will be found upon inquiry that either the tubes fail, for reasons given therein, or that such ratings refer to *short runs during a peak load,* and even then the utmost care must be taken to avoid tube failures. For example, in a recent case in which a water leg boiler with the least restriction found in such types, and for which large overload capacity is energetically claimed, was during an emergency compelled to operate under a *continuous* overload of only 75% above rating for *one day,* its safe limit was passed and 17 burned tubes had to be replaced, and these tubes were clean! Steam locking produced this result, which once more proves that such types cannot pass through the lower tubes sufficient water to prevent steam locking, as evident from Sects. 145, and 257 to 271.

484. What Maximum Rating the Kidwell Boiler Can Stand during continuous operation or during peaks, we do not know. The facts as given in Sect. 481 clearly prove that it can be run at many times that possible with any header type. No stoker has so far been able to produce sufficient heat under this boiler to distress it. We do know that this boiler has operated continuously day and night for 5½ months at 200% to 275% of rating, and for steady runs of 8 hours at 300% and higher, with furnace temperatures varying from 2800 to 3000 deg., not only without any distress whatever, but with reserve capacity left. In addition to this, *the water line was absolutely steady, and the steam superheated 30 to 37 deg.!* In view of the preceding computations such results are what would be expected, and quite higher ones with safety appear reasonable.

Note here that we refer to *continuous operation.* The capacity in peak loads will, as with other types, be correspondingly greater.

485. It is therefore clear that the Kidwell boiler may be operated at any rating which the stoker under it can produce, provided that it is kept clean, as necessary with every boiler, and in this connection it must be noted that the higher the rating at which any boiler is run, the more frequent its cleaning periods must be. On this point consult Sect. 114.

486. Rating Recommended. To increase the Efficiency of Capital it is necessary to work any tool, boilers included, up to its maximum economic limit. Therefore, purchasers of Kidwell boilers should, when determining what boiler capacity to buy, ignore *nominal rating,* and base their purchase on *actual capacity, then work the boilers at that capacity.* It is just as wasteful to underload a Kidwell boiler as to underload any other appliance. And again, it is even poorer financiering to judge all boilers by their price per nominal HP. of rating, and purchase one which has only limited capacity, so that when *judged as to what it can produce in return on the investment it may be far more costly than a good boiler offered at somewhat higher price!* This mistake is constantly made. See Sects. 89 to 99, 140 to 153, and particularly 227 and Azbe's remarks in Sect. 593.

487. Accordingly Kidwell boilers, if hand fired, should be operated continuously at the maximum rating the stack can produce. This will rarely exceed 150% of nominal rating, which even then does not work this boiler up to the point at which it should be operated to give the best returns on the investment. See Sect. 664.

488. If the boilers are fired by stokers, oil, gas, etc., so that high ratings can be developed, and are not equipped with economizers, operating continuously at 200% of nominal rating or more is entirely reasonable, and during peaks they should be run at higher ratings. If run at much less than 200% continuously, available capacity is simply being wasted, and the investment is not making the returns which are both possible and profitable.

489. If Economizers Are Installed in connection with the boilers, still higher ratings are practicable, safe, and economical, if the stokers can burn the necessary fuel efficiently. Since Kidwell boilers can operate at several times greater capacity than Fig. 102, and cannot steam lock their tubes if operated up to 500% of nominal rating, there is no reason, when economizers are installed, why these boilers shoud not be operated up to 300% of nominal rating and still higher during peak loads, if cleaning is done at such intervals as are necessary to prevent the formation of scale deposits sufficient to interfere with proper heat transmission, and if also the firing equipment can keep pace with the boilers. See Sects. 210 and 211.

490. Objection Anticipated and Answered. As the ratings above advised are beyond the safe limit of other boiler designs, and many boilers, if so operated, would certainly fail very quickly and probably with serious results, it is only natural that the above statements as to what can easily and safely be done by the Kidwell boiler will be violently criticized, assailed, or denied by some whose self-interest will be adversely affected by a general recognition of the above facts by boiler users. Their attack will be along three well defined lines, thus:—(1) Such practise severely strains a boiler and shortens its life; (2) When so operated there is a great loss of efficiency; (3) The brick setting cannot stand up under such ratings. We therefore anticipate and refute these arguments.

491. If so operating causes extra stresses in a boiler, these can come only from an increase in the steam pressure, or because of an increase in the temperature of the parts which will cause extra expansion, such as is discussed in Sects. 243 and 244. As to the first, nothing of the sort happens in any boiler with free circulation, because when operating at high ratings the *steam pressure is not increased,* hence the whole argument collapses, except to a small degree where, due to throttled steam and water passages, there may be an increase in the pressure below the up-comer exit, as shown in Fig. 37. In no case is this likely to reach serious proportions, but it cannot happen at all in the Kidwell boiler.

"The obstacles in the way of higher boiler capacities are *superficial,* and if the great advantage in the reduction of the first cost of the boiler plant is considered, it seems that *the high capacity boiler is bound to come in the near future.* This reduction in boiler plant will give steam power a greater advantage over gas power in large central stations."—Bulletin 18, U. S. Bureau of Mines, p. 140.

492. The second objection is a vital one as applied to boilers with deficient circulation. The moment a tube becomes steam pocketed it starts to overheat, with consequences shown in Sects. 43, 148 to 151, and 249 to 256, and Fig. 45. But as above shown, the Kidwell boiler has such free and rapid circulation that steam pockets are impossible at any practicable rating, hence the tube surfaces are always swept by water, therefore the tube cannot attain a temperature of over a few degrees greater than the water, hence cannot overheat, which disposes of this objection. Note final unassailable proof in Sects. 31 and 32, and the following clear-cut statement by D. S. Jacobus; also refer to second part of Sects. 183 to 186. "It is good modern practise to drive boilers daily at *double the nominal rating* during peak load periods. *This does not mean that the boiler is driven to an overload in the sense that it is under a strained condition of running,* as the rating of 10 sq. ft. per boiler HP. is simply an arbitrary one. The speaker believed that eventually boilers would be operated harder than this during peak load periods, and that additional plant economy would be secured thereby." —*The Generation of Power,* in *Journal of the Franklin Institute,* December, 1910.

Also note the statements of D. M. Meyers in Sect. 29 and Mr. Martin in Sect. 499.

493. The only trace of validity in this objection is that the higher the rating at which a boiler is operated, the greater the quantity of water evaporated, hence the more frequent the periods of cleaning must be, otherwise the tubes may become scaled through neglect, and thus burn out. That this is a valid objection cannot be admitted, as the facts are well understood by all good operating men, and there is no more excuse for neglecting the cleaning than for any other gross negligence not to be permitted in any well conducted power plant.

494. The Bugaboo about Decreased Economy at the high ratings is equally imaginary. Reference to Sects. 183 to 186 will show that just the contrary is true, and also indicate the usual motive behind statements to the effect that operating at ratings as above suggested is not feasible or advisable. To supplement the above the following is quoted from the article of Dr. Jacobus just referred to. "In power plant practise it would pay to run the boilers at a high rating during peak load periods even though the efficiency should fall lower than this (60% in the case referred to), because a great saving is effected in cutting down the fuel required to keep banked fires in the boilers held in reserve and to bring up cold boilers to be run during the peak load intervals. With * * * stokers, such as were described * * * the best efficiency is reached at slightly over rating and *remains constant to nearly double rating*. The reason for this is that *as the rate of combustion of the coal becomes greater the furnace efficiency increases* to a sufficient extent to offset the loss of heat absorptive efficiency of the boiler. It is therefore apparent that under these conditions the best *commercial economy* is obtained by following the practise described and operating the boilers at *double the nominal rating*."

495. Finally, see Sect. 25, Art. (b), which epitomizes the experience of decades of power plant development, and represents current practise in all plants of advanced design today. Any statement to the contrary represents failure to keep up with present progress, or *desire to sell equipment unequal to the demands of modern engineering practise!* As confirming this, note the following from Mr. Victor J. Azbe, in *Mechanical Engineering*, for November, 1921, subject *Boiler Plant Efficiency*:—"It is the writer's experience that the very large majority of plants possess and operate too many boilers, *at times twice as many as necessary*. The cry is, 'Give us plenty of boilers,' and the result is waste in investment and waste in operation. Since high boiler efficiency at low ratings is more difficult to obtain than at high ratings, it follows that owing to this and also for investment reasons, *boilers should be installed designed for high overloads* and high and constant efficiency over a considerable capacity range. Especially in plants where the load varies a great deal the boilers should be able to take the peaks; even if these peak loads are somewhat uneconomical they are to be preferred to boilers loafing the greater part of the time. As a rule good boilers, well installed, should be operated at between 150% and 200% of rating, and when a peak is of short duration 300% of rating is permissible. Ratings below 150% should not be permitted except under unavoidable circumstances." With a Kidwell boiler the higher rates herein advised may be kept up *continuously*, if sufficient stoker capacity is provided together with draft equipment to remove the gas.

"The efficiency obtainable from the boilers is not the only factor that governs the efficiency of the plant as a whole, especially under variable load conditions. The variation in the load must naturally be taken care of either by operating the boilers at widely varying capacities or by carrying banked boilers which are cut in at the time of the peak loads. It can be readily appreciated that should the boilers at a plant be limited to a capacity of 200% of rating, a greater number of boilers would have to be in continuous operation or a greater number of boilers would have to be held in reserve for cutting in during the peak load interval than were it possible to operate the boilers at the peak load intervals at 300% to 400% of rating. By arranging to operate the boilers at 300% to 400% of rating they would ordinarily not give as high an efficiency at the lower ratings as the boilers having having stokers especially fitted for operating at the lower ratings, but when it comes to the efficiency of a *plant as a whole*, a better efficiency would ordinarily be secured by the use of boilers capable of being operated at the higher ratings even though these boilers might be, say, 2% less efficient at a given rating than the boilers having a more limited capacity. *The obtainable capacity is therefore an important factor*, especially when the load is variable. In the event of extreme variations which come at rare intervals it can be readily seen that the ability to carry the load far offsets any loss in economy when running at the higher load, and it is these elements that have caused the capacity at which boilers are run for peak load service to be advanced to 300% or even 500% of rating." —*Boiler and Furnace Economy*, by D. S. Jacobus, in *Mechanical Engineering*, December, 1921.

Lastly, refer to *Power*, January 3, 1922, p. 4, wherein it is stated with reference to the Colfax plant at Pittsburgh that "it was considered that *the lowest yearly cost* in the boiler room would be obtained by operating at 200% to 225% of normal rating."

496. The answer to the third objection that the brick setting cannot stand high ratings is contained in the above proof that such method of operating *is now standard practise* in large power plants which are up to date. This would be impossible if such procedure caused rapid and frequent failure of the furnace lining.

Here it is necessary to correct a widely prevalent, but wrong belief. Many who are not posted on the details of combustion assume that if the boiler rating be increased so that more coal is burned in the furnace, then the *furnace temperature is greatly increased also.* This is not usually so. If a pound of coal be burned with say 16 lbs. of air, a certain temperature will result; if now a ton of coal be burned with the *same quantity of air per pound, the resulting temperature will be the same as before,* though the quantity of heat or B. T. U. liberated will be increased in proportion to the weight of coal burned. Unless this heat is removed from the furnace as fast as it is liberated, it will be soaked up by the furnace walls, as in a crucible, and the walls will overheat and deteriorate. But if proper draft be applied so as to remove the gas as fast as formed, there will be but little increase in the temperature of the furnace walls, hence, *operating at high ratings requires ample draft,* as fully explained in the chapter on stacks starting with Sect. 601.

497. Our observation has been that more furnaces overheat and fail at low ratings than at high ratings, solely because of deficiency in chimney draft, and attempts to increase the capacity by using forced draft in the ash pit. This will invariably overheat the furnace walls, yet fail to produce the desired capacity, unless sufficient chimney draft is supplied to produce a slight vacuum over the fire, as shown in Sect. 684. Also, see analogy in Sect. 579. But, if these details are properly taken care of, operating at high ratings is entirely feasible and satisfactory, as proved by the standard practise in plants in which every available means of producing economy are employed. "One objection to high CO_2 is the extremely high furnace temperature and consequent rapid depreciation of furnace linings. * * * On the Detroit Edison boilers, however, where CO_2 is maintained at from 15% to 17%, the furnace lining *shows no effect of high temperatures.*"—Victor J. Azbe in *Power Plant Efficiency,* A. S. M. E. Transactions for 1916.

498. For developing high ratings efficiently, ample furnace volume and height are also essential. See Sects. 156 to 170 and 541(a). All such details must be fully considered when making a boiler purchase. Valuable information as to this is given in *Are Refractories Imposing a Limitation on Stoker Performances?,* (being S. S. Bulletin No. 2 of Laclede-Christy Co., St. Louis, Mo., November, 1921), as the following will indicate:—"Another abuse of furnace linings comes along with still another old story—that of low boiler settings. If the high rate of heat development possible with forced draft stokers is permitted to take place under low-set boilers, one can look for refractory troubles. If confined to a small furnace volume, the usual quantities of heat developed by forced draft will be concentrated on the limited extent of linings, and often this condition is made worse by an unusual impinging of the flame upon the refractories—a sort of scouring action accentuated by the small confines of the combustion chamber."

499. The matter is thus summarized by Mr. Chas. L. Hubbard in *National Engineer,* November, 1921, p. 567:—"Mr. Kingsley Martin states that the recent tendency in modern power plants has been to operate boilers at from 200% to 300% rating, and in some cases as high as 400%, for hours at a time; and furthermore, while this may be considered 'forcing' and likely to result in tube trouble and high maintenance cost, *it is not necessarily so when the furnace is correctly designed and the boilers properly baffled.*" What is even more necessary is speed of water circulation, which this writer fully realized and showed elsewhere in his article.

500. Additional Features Necessary for a Good Boiler. Up to this point the operation as explained has been confined to what can be done with a boiler of the general form of Fig. 179, which is Fig. 138 perfected as to proportions and detail, but not changed in principle. If the design were carried no farther it would still surpass all other present and past types as to free circulation, capacity, prevention of tube overheating and general simplicity. But as pointed out in Sect. 350 it is lacking in steam space, water endurance, and ability to deliver dry steam. If an attempt is made to remedy these deficiencies by so increasing the diameter of drum No. 3 in Fig. 149 as to obtain the necessary steam space and water surface, the latter alone will require the drum diameter to be dou-

bled. Apart from the excessive and impracticable thickness of plate so needed when operating at high pressures, this would require a prohibitive increase in space, and decrease the safety by violating a cardinal principle of design in water tube boilers, namely that drums of excessive diameter be avoided. Contrary to the general impression, such large drum diameter will not produce dry steam, as proved in Sects. 85 to 87, and illustrated in Fig. 92.

501. Bubbles of steam emerging rapidly from the water will *always be wet and scatter spray which emulsifies with the steam!* For example, notice the water bottle in Fig. 79 and how when the air bubbles disengage they invariably scatter a spray of water. If this be so when only a few cubic inches of air emerge from the water, it is clear that when a *mixture* of steam and water is gushing out of a tube, water in fine particles will be scattered in every direction. That is one fact established beyond controversy, and the only way to get *DRY* steam, or steam containing *NO* moisture, is to dry it after it is disengaged from the water. This is true, regardless of the design of any boiler, or what kind of water is fed into it, whether dirty, foamy or chemically pure. Since, as shown in Sects. 46 and 47, it is the rising bubbles of steam which cause circulation, and further because the greater the depth from which the bubbles are rising the greater their velocity is, it follows that when steam is disengaged from any water surface beneath which terminate numerous up-comer tubes, the water adhering to those bubbles will be ejected up into the steam space, and be emulsified with the steam, so the latter will *always be wet when disengaged,* regardless of any claims to the contrary. See Sect. 88.

Therefore, the next essential step in perfecting the design of the Kidwell boiler was to devise means of overcoming every defect above pointed out, and the methods used will now be explained. These must be clearly understood as an incredible amount of twaddle has been written in the hope of creating a contrary belief.

502. Obtaining the Necessary Steam Space and Water Endurance Surface. While at first glance it would seem easy to supply these required features, the problem of doing so in such a manner that they *operate satisfactorily* has been, as said in Sect. 396, the most difficult one met in developing this boiler, and is the one which has baffled all previous designers, as shown by the references below. Obviously it is easy to add on top of the boiler an additional drum of such size that the sum of its diameter and that of drum No. 3 in Fig. 149 will provide the necessary water surface. It may, *on paper,* but that it *will not when in actual operation* is exemplified by Fig. 105 and study of the action of Figs. 103, 140, 141, 143 and others, in none of which the water in the various drums will or can remain at the same level. See Sects. 62 to 66, 266 to 271 and 297 to 300. In the analysis of the sundry designs already discussed, it will be seen how invariably fluctuation of water line causes constant trouble and frequent disaster. The grave importance of this and the disastrous consequences of ignoring it are such that every plant operator and boiler buyer should thoroughly study it. Any doubt as to that will be removed by referring to Sects. 58 to 66 and the references given therein. The reader will then quickly perceive that the problem of eliminating such differences in water level is an extremely difficult one. Sects. 62 to 66 and 266 to 271 show unsuccessful attempts of European engineers to overcome this evil.

503. As explained in Sect. 396 the solution of this problem required the working out and practical application of some principle previously unknown in boiler design, and this was finally accomplished, as already explained in the Section above referred to.

504. How Steady Water Level is Obtained. As the problem of accomplishing this was not solved until this new principle was discovered, it is essential that it be clearly understood. The essence of it is to provide a main water circuit so arranged as to generate and deliver the steam into a disengaging chamber without causing violent fluctuation of water level in that chamber, and then to provide a second circulating system so arranged that its main function is to maintain substantially the same level in the two or more top drums containing steam and water.

This is fully protected by United States and Foreign Letters Patent both as to mechanism and process.

505. Application of this Principle. We have worked out many ways of applying this as occasion arises, but the standard method is shown in the sundry drawings of our boilers as given in this book. Figs. 185 to 187 show a diagrammatic representation of the disposition of the parts and their action. The drum on the left is the disengaging drum and that on the right is the outlet drum, these two being connected by

ARRANGEMENT OF KIDWELL BOILER WITH EXTENSION FURNACE FOR BURNING HOGGED FUEL.

SEE PHOTOGRAPH ON PAGE 258

steam over-comer tubes as shown in Fig. 186 and marked 9 in Figs. 147 and 149. Two submerged tubes marked A connect the drums near their ends, and are so inclined that the water

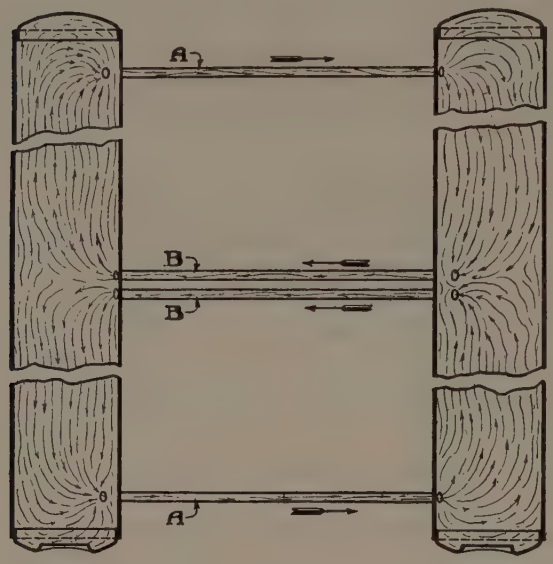


FIG. 185. PLAN AND SECTION THROUGH DRUMS

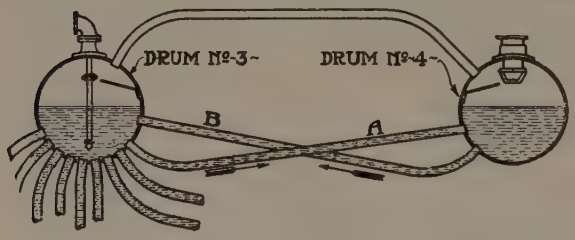


FIG. 186. SECTIONAL ELEVATION THROUGH DRUMS AND TUBES OF SUPPLEMENTARY WATER CIRCUIT

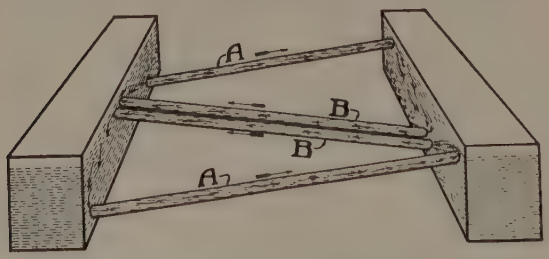


FIG. 187. DIAGRAMMATIC PERSPECTIVE, IN WHICH TANKS REPRESENT THE DRUMS

flows or circulates from left to right as shown by arrows. Near the center of the drums two tubes B are so placed that the water flow is *in the reverse direction,* and thus these tubes and the drums constitute an independent and auxiliary water circulation whose sole function is to keep the water in the two drums *at identical levels!* The perspective in Fig. 187 also shows the arrangement; in this, rectangular tanks have been substituted for drums to enable the action to be easier understood.

Mechanically this arrangement is the acme of simplicity. But it is impossible to show a photograph of the actual structure because beam 45 in Fig. 149 cuts off part of the view. But by a little study Fig. 188 will make the construction and disposition of parts clear.

In these views the tubes connecting drums 3 and 4 are lettered A and B precisely as in Fig. 186. In the second tube bank of the boiler the first four tubes starting from the top are lettered C, D, E and F.

In the plan the tubes A and B are shaded heavier than the others, and in the elevation the tubes immediately behind the plane where the section is taken are shaded, while others in the adjoining row behind are not shaded.

On each side of the boiler, in the vertical row of tubes next to the wall, tubes C and D are omitted, and by so doing the necessary space is obtained for inserting tube A so pitched that the water flows in a direction opposite to that in the other tubes.

In the center of the boiler two parallel tubes C are omitted, and in lieu thereof two parallel tubes B are substituted, and the flow in them is in the same direction as in tubes C, D, etc.

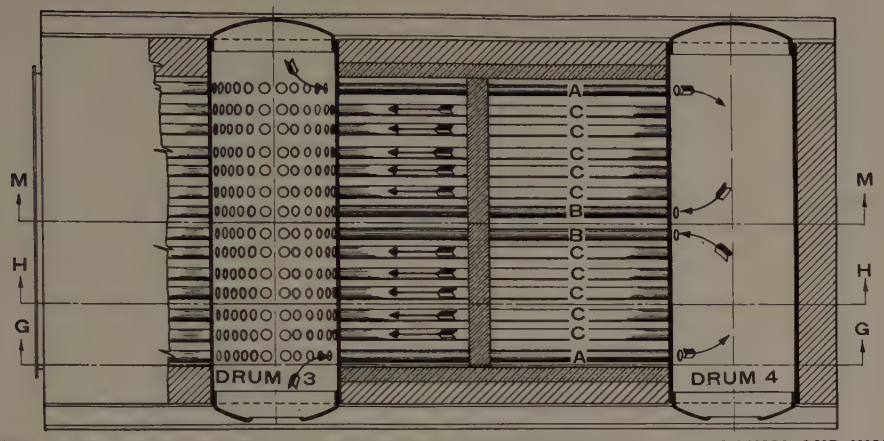
Thus the two tubes A and two tubes B conconstitute the minor water circuit between drums 3 and 4.

But in the actual design of the boiler the number of pairs of tubes A and B used depends upon the width of the boiler. For small or narrow boilers only one pair is used, but as the width of the boiler and the furnace is increased the number of pairs is increased to two or three, etc., as may be necessary.

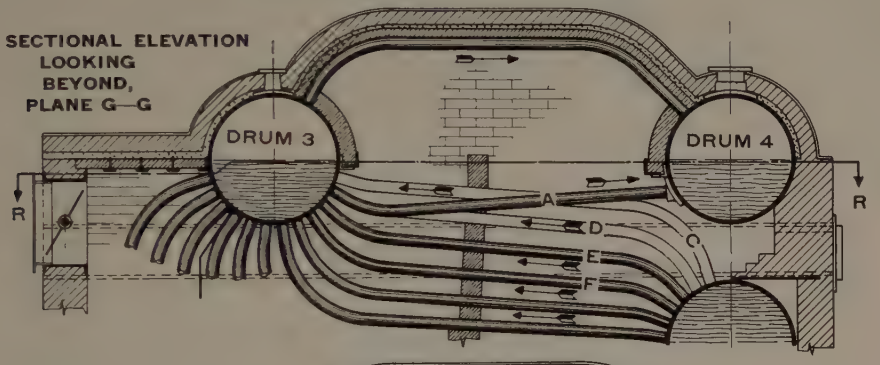
In all tubes the water flow is in the direction shown by the arrows.

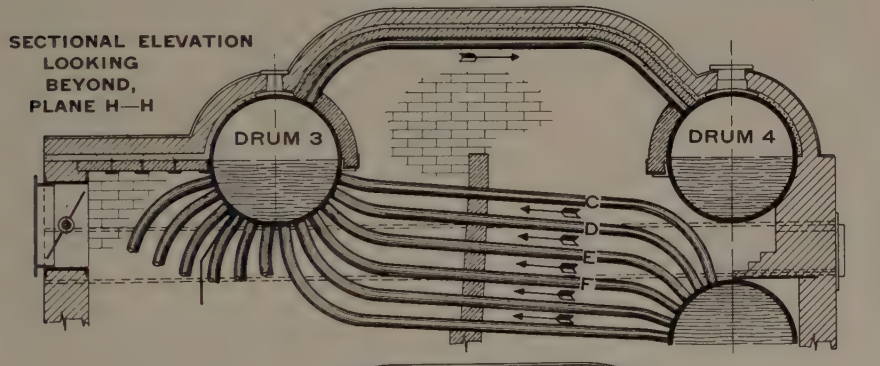
506. The action of the arrangement just described is perfect. With the boiler operating steadily at 200% to 400% of rating, load rapidly fluctuating, safety valves frequently popping, and no feed regulator used, the level of water in the glass did not as the changes occurred show any sudden movement whatever which was perceptible from the firing floor level.

507. Mechanical Analogy. In Fig. 189 let the 3 large pulleys and the belt running over them duplicate Fig. 181 and illustrate the main



SECTIONAL PLAN ON PLANE R—R IN WHICH INSULATING BRICKS AROUND DRUMS AND WATER IN DRUMS ARE OMITTED FOR CLEARNESS





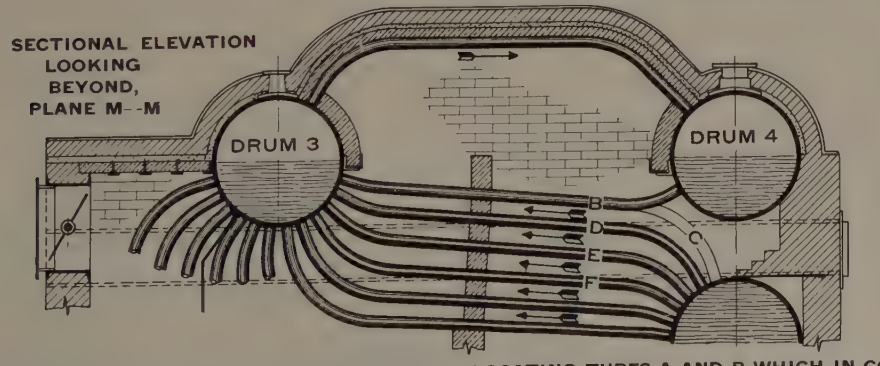


FIG. 188. SHOWING ACTUAL CONSTRUCTION USED FOR LOCATING TUBES A AND B WHICH IN CONJUNCTION WITH DRUMS 3 AND 4 CONSTITUTE THE SUPPLEMENTARY WATER CIRCUIT WHICH CONTROLS THE WATER LEVEL

circulation in the boiler. Add the two smaller pulleys A and E, and connect these with a crossed belt. Then the whole system works in unison and is a perfect mechanical analogy of the water flow in the Kidwell boiler.

508. Thus by the application of our new principle fluctuating, uncertain and dangerous variations of water level are eliminated from the Kidwell boiler, and this has the far-reaching consequences stated in Sect. 3. It may also be justly compared with Gayley's process for eliminating moisture from the air entering the blast furnace. Previous to Gayley's invention nobody could tell what grade of iron would be produced, as it depended upon the fluctuation in the

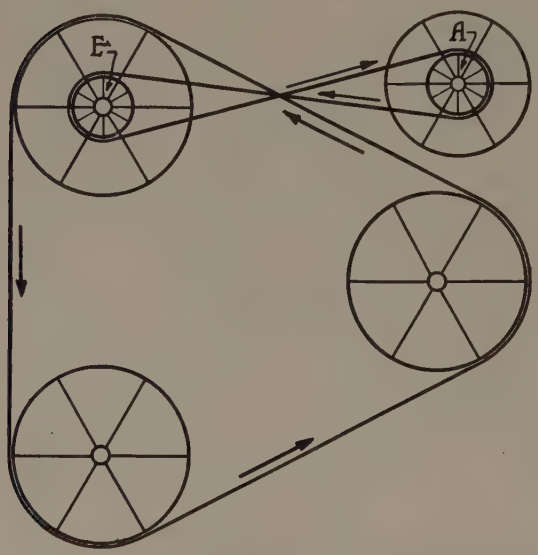


FIG. 189. MECHANICAL ANALOGUE OF CIRCULATION IN BOILER WITH TUBES ARRANGED AS IN FIG. 186

amount of aqueous vapor in the air. After Gayley eliminated this, the performance of the furnace could be gauged exactly and its output be made uniform as to quality.

Similarly, in other boiler designs the water level is equally dubious, and frequently one part of the boiler is uncovered and exposed to danger of overheating and rupture, even though ample water is indicated by the glass. See Figs. 11 and 12. In the Kidwell boiler this danger is completely eliminated, and the glass shows the water at the level which exists throughout the entire water surface.

In consequence, capable engineers whose judgment is based wholly on *results* consider this improvement the most important and far reaching that has appeared for the last half century. That this is so will appear from the following:—

509. Constant Water Endurance Surface. Sects. 78, 79, 298, 354, 356, 365 and others prove the necessity of this, and how often the *real surface* is but a fraction of the apparent surface, and at times only a small fraction. Since in the Kidwell boiler the water level in the top drums remains identical regardless of fluctuation in the rate of driving the boiler *the water endurance surface remains constant!* Compare with Fig. 105 and note that there the *effective* water endurance surface is only 40% of that in the Kidwell boiler, hence 2½ times the vigilance is necessary in order to avoid low water and burning of the sheets. Refer also to the account of *San Diego* explosion in Sect. 235(b) in which 5 boilers were overheated because of small water endurance surface and necessity of carrying the water low to avoid priming.

510. It is evident that the higher the rating at which a boiler is to be worked and the more intermittent or fluctuating its load, as when operating rolling mill or hoisting engines, the greater the water endurance surface should be, *though this is seldom realized until too late!* That European engineers have realized it is shown in Sects. 266 to 271. This Company has boiler sections adapted to every class of service, with water endurance surface ample for any fluctuation of load.

511. Fuel Saving Due to Steady Water Level. It is not generally known that constantly fluctuating water level in a boiler causes a fuel loss, though it does. Carefully conducted tests several times repeated have shown a considerable difference. See Catalog of The Berry Engineering Co., Chester, Pa., pp. 15 to 20. Thus by maintaining the water level steady, not only is operating made easier, but fuel is saved.

512. Disengaging Surface. From Fig. 149 it is clear that above *each individual tube* is ample surface for disengaging the steam similarly to the action in Fig. 40, whereas in header types the effective disengaging surface is only that over the nipples in Figs. 35 and 65, or over the openings between bridge pieces in Figs. 74 and 75. Accordingly, the quantity of steam released per square inch of active disengaging surface in the latter designs will be far greater than in the Kidwell boiler, hence the steam will cause more spray in the drum, therefore priming action will be more violent. Yet even with this difference in favor of the Kidwell boiler the steam as dis-

engaged will necessarily be somewhat wet, hence for the vital reasons given in Sects. 89 to 99 it is necessary in *every boiler approximating perfection,* to devise means whereby the steam can be thoroughly dried. A further reason for doing this is to prevent sediment being swept into the mains, for which see Sects. 531 to 535.

credit than he has received, hence we are glad to present here our tribute to him. His method is used in the Kidwell boiler as follows:—In Fig. 149 the steam from drum 3 passes through the tubes 9 which not only dry it thoroughly but superheat it from 5 to 40 degrees, or even more, according to the kind of fuel, and rate and

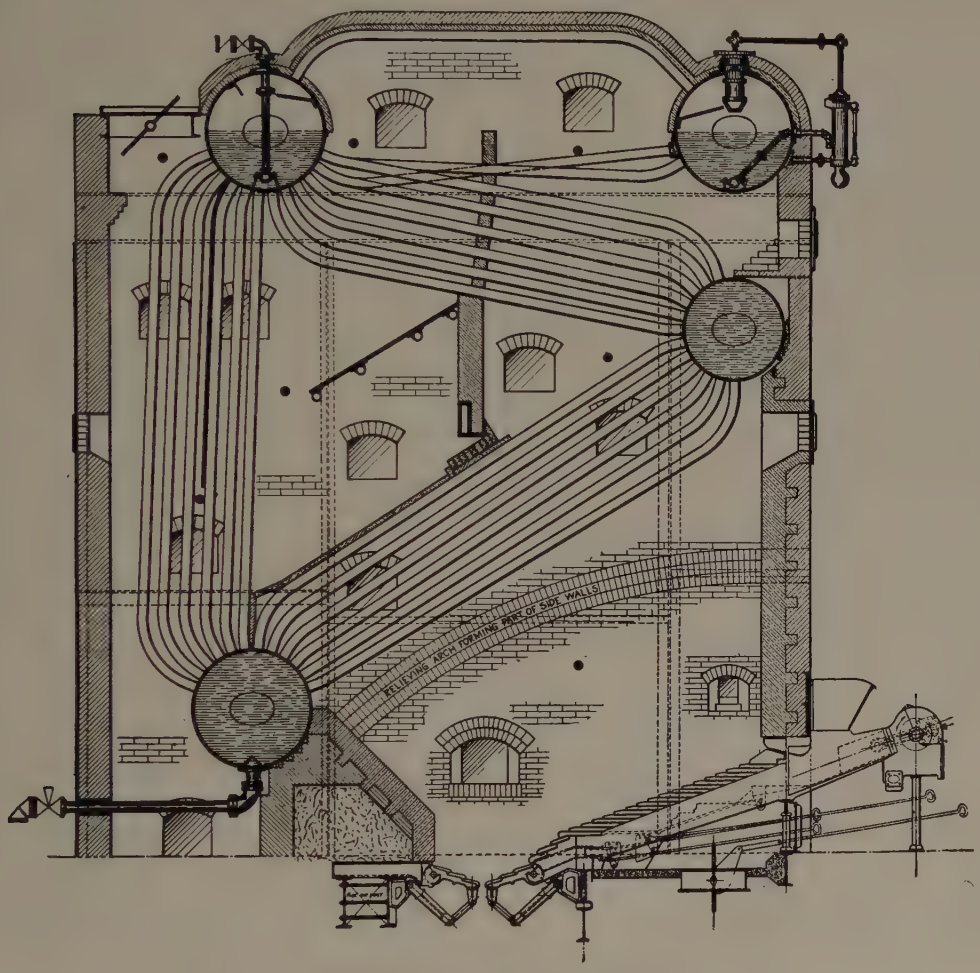


FIG. 190. KIDWELL BOILER AND WESTINGHOUSE STOKER

513. How the Steam is Dried and Superheated. While the pernicious consequences of wet steam have long been known, it seems strange that boiler designers have timidly shirked the task of devising means to overcome such trouble. Not all did so, however, and about 40 years ago Robert Zell of Baltimore neatly solved the problem by installing overhead drying tubes swept by gases of medium temperature, as shown in Figs. 23 to 25 (top tubes over the drums), and this proved a success. Nothing better has ever been devised and he deserves far more method of burning it. In Fig. 163 the baffle A (18 in Fig. 149) is so placed that the superheated steam impinges upon it and is directed toward the steam collecting pipe B, so that it does not even ruffle the surface of the water in this drum. Further, since the water does not fluctuate as to level it has no tendency to mix with the steam and reduce the superheat.

514. Since the above was written it appears that because of survival of erroneous ideas current 20 years ago before practical experience with superheat had exposed the fallacy of many

previous assumptions regarding it, and the dearth of literature showing the present state of knowledge on this subject, it is necessary to explain three things:—(a) That though steam be superheated it can still contain and convey water in suspension or emulsion; this is covered in Sect. 103; (b) Why steam passing through the superheating tubes marked 9 in Figs. 147 and 149 does not lose its superheat on its way through tubes 9 *does not impinge upon the water surface, but passes directly to the collecting pipe 17.* Therefore, there is nothing to bring the steam and water into intimate contact, or to emulsify them, hence any heat transfer from steam to water is too trivial to produce a noticeable result. If the deflecting plates 18 were omitted and the steam were allowed to spray itself onto the water surface, a proportion of the

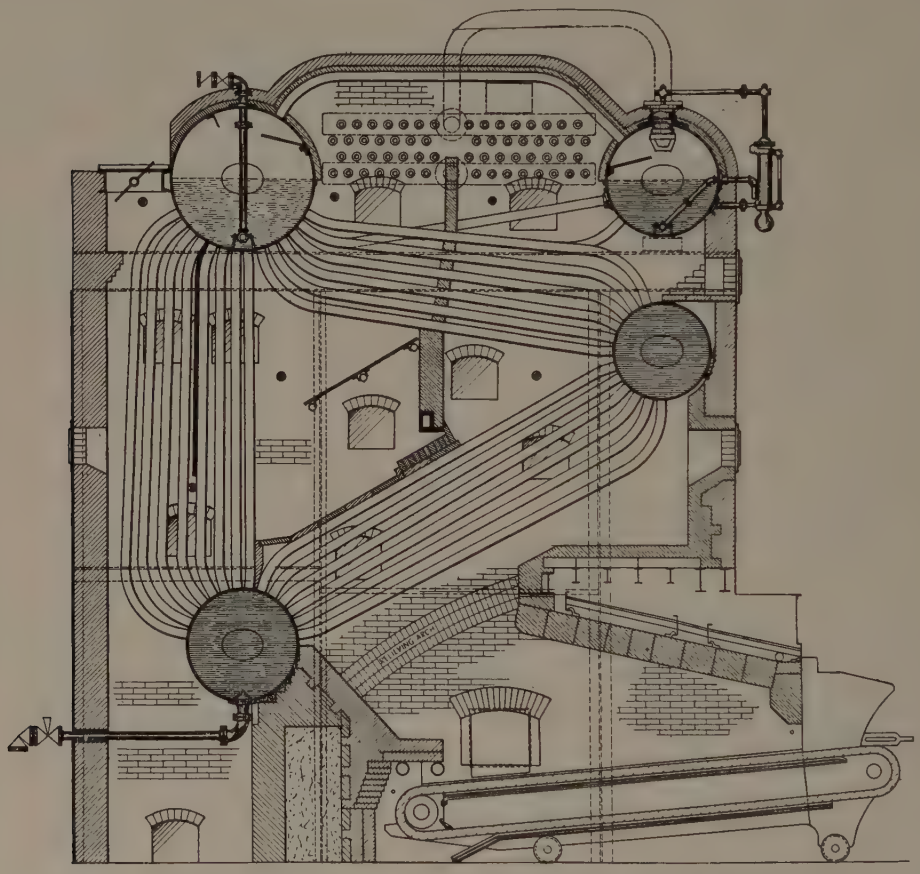


FIG. 191. KIDWELL BOILER, GREEN CHAIN GRATE AND FOSTER SUPERHEATER

through the outlet drum No. 4; (c) Why the tubes marked 9 do not overheat and burn. Accordingly, the last two will be taken up.

515. Why Steam Does Not Lose Its Superheat When Passing Through the Outlet Drum. The key to this is contained in Sect. 103. Steam has very poor heat conductivity as compared with water, hence does not quickly pass its heat to water unless the two elements are thoroughly broken up and emulsified. Inspection of Figs. 147 and 149 shows that because of the baffle marked 18 (or A in Fig. 163) the steam flowing superheat would then be lost. Hence it is clear that such deflecting plates are necessary for producing the degree of superheat shown in Sects. 91 to 95 to be essential. In consequence of this construction the Kidwell boiler delivers steam superheated 10 to 60 deg. according to the kind of fuel used and method of firing it, and has produced more than that when operating at high ratings. Further, because of the deflecting plates above mentioned, *the steam cannot pick up slugs of water, hence the steam is not only superheated, but is free from entrained water also!*

The beneficial effect of this arrangement could not be better described than the following from *Superheating,* by Heine Safety Boiler Co.:—"It may therefore be said that by using superheated steam there is obtained a fuel economy equal to half the steam saving. *This means that heat imparted to a superheater is just twice as valuable and generates twice as much power as heat imparted to a boiler.*" The benefit thus clearly defined is, of course, additional to the saving of 5% to 10% mentioned in Sect. 96 as resulting from elimination of all moisture from the steam.

516. Notwithstanding that the statements above made have been verified times without number, their accuracy is sometimes questioned by those to whom "the wish is father to the thought," hence entirely disinterested confirmation at least 17 years old will be given.

517. In *Journal of Franklin Institute,* October, 1906, Mr. A. S. Mann published *Superheated Steam in Power Stations* in which he described the results of a superheater installed in a boiler of the general design of Fig. 102. The middle pass of water tubes shown in this figure was omitted and in lieu thereof a superheater installed, and its construction was as follows:—"The superheater is made up of two horizontal drums about 8 ft. apart, one placed almost directly over the other with 2-inch tubes extending from the lower to the upper drum. Steam enters the upper drum, makes two downward and two upward passes between the drums and leaves the upper drum to go to the steam system."

This was tried out over a wide range, up to producing 320 deg. of superheat, with results as below described.

"It has been found that it is possible to have superheated steam and water in the same vessel. This is true even when every opportunity is given to steam to pick up the water and diminish its own superheat. There is no deposit of water in the lower drum while the boiler is making steam. If, however, the boiler stops steaming and the fires are held in check long enough to allow the furnace gases to cool down, there is a deposit of water in the lower superheater drum. If this water is allowed to accumulate, there is a very considerable amount to be dealt with in the morning, 4 or 5 inches along the bottom of the drum perhaps.

"When the fires are brought up again the outgoing steam is superheated in a very short time fully up to the regular average; *but the water in the bottom drum is not absorbed by the hot steam sweeping over it. The surface of the water being some twenty sq. ft. in area, the steam superheated on an average of 100 deg. passing over it at the rate of about 3 ft. per second, it would appear that this whole volume of water should be taken up and made into steam in less than 30 minutes, particularly as the water itself is at the boiling point, or very near it. This water is NOT taken up by the steam, however. It lies in the bottom of the drum until it is drawn out through a drain pipe.*"

This clearly proves:—(a) That the old notion that superheated steam cannot exist in a vessel containing water was long ago disproved, and (b) that superheated steam passing over water in headers or drums will not evaporate that water, *hence superheater headers need facilities for drainage.* This latter fact is even yet not so well understood as it should be.

518. Why the Superheating Tubes in the Kidwell Boiler Do Not Burn Out. That they do not has been proved by years of actual performance. These boilers have been operated for long periods continuously at ratings which would destroy many other designs of boilers, yet the superheating tubes have not even developed a leak. The reason is that the rapidly flowing steam absorbs the heat transmitted through the tube walls precisely as in case of a tube conveying water, for which see quotation from Technical Paper 114, in Sect. 31. *This applies to all forms of superheating devices,* and will prevent them from overheating unless the tubes are exposed to extremely high temperature. Mr. Mann's paper above cited clearly shows this, thus:—"When one of these boilers was first started up it was felt that great care should be taken to avoid overheating the superheater tubes. Provision was made for flooding the surface exposed to the gases and the superheater was filled full of water and gradually drawn down until it was filled entirely with steam as the fires gained in temperature and steam was raised so that there was a flow through the tubes. *There is a disadvantage, however, in that there may be a deposit of very dirty water in the superheater tubes and the ability to start in a simple way is to be desired. It was found on trial that it was unnecessary to flood the superheater in starting new fires and that the tubes and joints would withstand any stresses put upon them provided the fire was started slowly, perhaps a litle more slowly than would be considered safe practise with a regular saturated*

boiler. Starting with a dry superheater with slow fires has been proven to be safe practise and no trouble whatever has been experienced from this method.

"It is possible by forcing fires to increase the degree of superheat to 320 deg. Fah., giving a final temperature to 692 deg. *and even at this temperature there is no trouble with the superheater though the gases entering the superheater bank are well on to 1200 deg. in temperature.*" perature of the gas sweeping the superheating tubes is far lower than that of the gases when they reached the superheater in the case above described by Mr. Mann, and shown by him to be entirely safe, and to cause no trouble. Therefore, in the Kidwell boiler the security against overheating is still greater, to the extent shown by the above differences in gas temperature. This has been confirmed by more than 40 years of actual satisfactory use, from the superheating

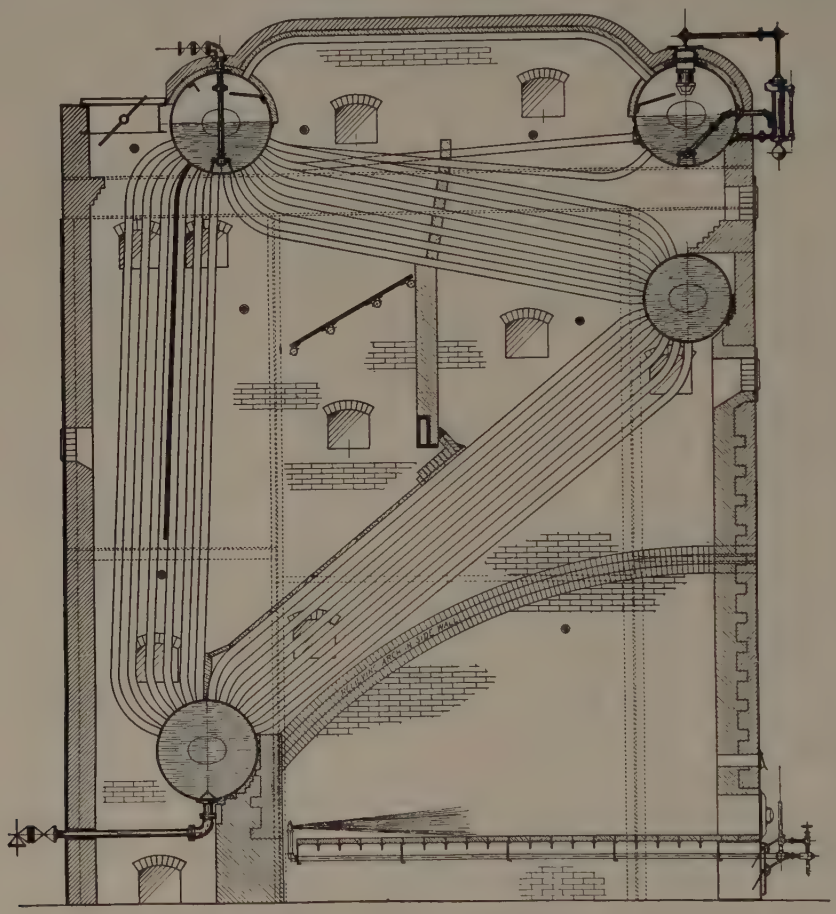


FIG. 192. KIDWELL BOILER ARRANGED FOR OIL FUEL

From Fig. 102 it will be seen that the gases reaching the superheater above described had passed over not more than 35% of the boiler surface, whereas in the Kidwell boiler the gases pass over 50% to 52% of the heating surface before they reach the overhead superheating tubes. From Fig. 175 it will be found that the extra proportion of heating surface passed over in the Kidwell boiler represents in curve "a" a temperature drop of 260 deg., and in curve "b" a drop of 500 deg., hence in this boiler the tem- tubes in the Zell boiler, Fig. 23, and similar devices, up to the latest development in the Kidwell boiler producing with entire success and safety continuous superheats up to as high as 65 degrees.

☞Note the objection of Mr. Mann to the flooding of superheaters. This objection is well founded, and such flooding will invariably cause scaling of the superheater tubes which will soon cause them to burn. The same result is caused by *dirty steam!* See Sect. 534.

And for the same reason, boilers which carry over water into the superheater will *also carry mud and scum* which likewise cause superheater tubes to burn. The Kidwell boiler is free from this highly objectionable feature, for which see Sects. 534 to 536.

519. The Steam Collecting Pipe "B" in Fig. 163 is *not a dry pipe,* as the steam is already superheated. Its function is twofold:—First, to draw the steam out at the top as it flows over baffle A, and thus obviate any tendency to lift the water below: such tendency is here very little because the water in this drum is *not connected by tubes to any body of water below,* hence as shown in Sect. 86 the "pop-bottle" action due to a sudden drop of pressure in the drum is nullified; contrast this with the action under the nozzle of Figs. 68, 92, 101, 102, 105, 121, 137, 143, 78B and others, as explained in Sect. 304: Second, *a capable engineer tries to foresee and provide against even remote contingencies as to accidents!* Rupture of a pipe line fitting is not very frequent, *but such things do happen* and it is but common prudence to guard against them. In such case the instant reduction of the steam pressure in the boiler to almost zero will cause a "pop-bottle" action which will almost immediately eject most of the boiler contents with great velocity. This will surely cause burning of tubes and sheets, and may even rupture the boiler because of the violence of the impact of the water against the top or sides of the drum, as clear from Sect. 85. Cases have been known in which drum heads have been blown out from this cause.

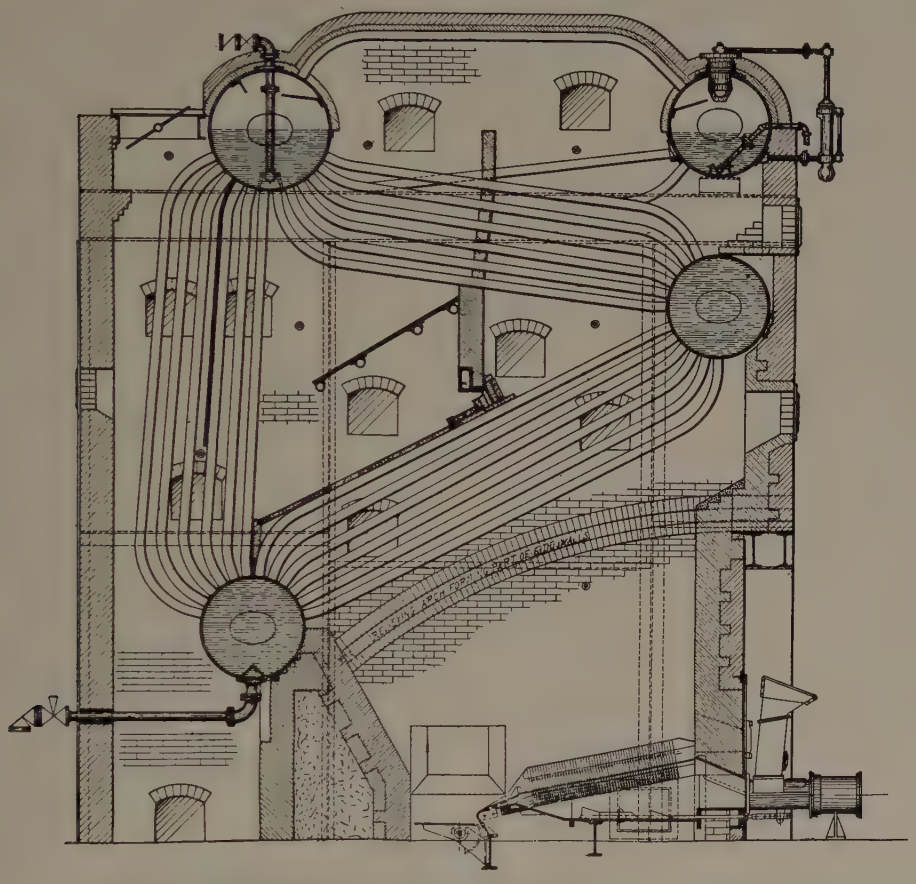


FIG. 193. KIDWELL BOILER AND JONES AUTOMATIC CLEANING STOKER

This is prevented by inserting the pipe B, Fig. 163, in which the steam has to pass through a multitude of small holes so arranged as to act as a shock absorber in case of a rupture of any part of the steam line.

In cases where a superheater is used that will serve the same purpose so that pipe B is omitted.

520. Saving Due to Drying and Superheating the Steam. Sects. 89 to 99 so fully cover

this that all that need be added here is that *this one feature* of the Kidwell boiler will justify any purchaser, who is looking for the greatest return on his investment, in buying this boiler rather than accepting gratis any other now on the market as shown in Sects. 98 and 99. In further evidence thereof we quote the opinion of a most eminent authority, Mr. Bruno V. Nordberg, who says:—"The value of dry steam in a power plant is not generally appreciated. In cases where I have to make economy guarantees on steam plants, based upon the actual amount of *Coal* burned, and when a water tube boiler will have to be used, *I would specify in every case that such boiler be provided with some steam drying device.* * * * It is my opinion that *every* boiler should be fitted with such device."

Just as this book was going to press a client sent in a statement so confirmatory of the above that it will be inserted here. "We should also consider the advisability of using *absolutely dry steam from a boiler* rather than trying to dry it by the installation of superheaters. We might explain that it is foolish to try to dry wet steam with superheated steam such as we have in some plants where they have quite a number of boilers operating but probably only one or two of them with superheated steam, all boilers discharging into one main header, *with the idea that the superheated steam will dry up the wet steam. Our experience has proved beyond question that this is not successful.*

"I have one particular case in mind where we installed * * * boilers to operate turbines. On making a test on the water rate we found that these turbines were using over 40 lbs. of water per K.W. Our thermometer at the throttle valve showed that we had the proper temperatures according to pressure and superheat, and it was some time before we found out that the boilers were priming badly, so much that *the water rate was actually doubled on the turbine, without affecting the thermometer.*"

The moral of this is, buy boilers which deliver *steam already somewhat superheated,* rather than an emulsion of steam, water and mud.

521. There is not today any easier and cheaper way for plant operators to save money than to use a reasonable amount of superheat. In fact, it is almost beyond belief to note how much money is spent in other ways that bring far smaller returns, yet superheat is ignored, and boilers which prime heavily are purchased *simply because they are low in first cost.* By the time they are ready to operate this imaginary saving is usually more than wiped out, as shown above and in Sect. 139, and the buyer then penalizes himself with the task of paying for wasted fuel for at least 25 years because he did not realize at the start that purchasing an inefficient boiler is "saving at the spigot and losing at the bung," and this is intensified in case a superheater is used, as proved in Sect. 534. Some further information is given in *Superheating with Reciprocating Engines,* in *Power,* June 1, 1920. Also see Sect. 101.

Clients should realize *that the more wasteful their plants are, the more boilers they must buy,* which fact eliminates any question as to the above suggestion being made by us through self interest.

522. Adaptation of Kidwell Boiler to Superheater Installations. The majority of boilers now purchased, especially if of large size and for high pressures, are equipped with superheaters, hence it is a matter of considerable importance whether a boiler is so arranged that these superheaters can be so installed as to be accessible, and able to develop the desired degree of superheat. *Most boilers on the market originated before superheaters were in successful use, hence they made no provision for applying superheaters!* In consequence, many attempts to install them in such boilers result in extreme complication, insufficient superheating capacity, inaccessibility of parts, lodgements for dust and ash, and the general poor proportioning. "Most of our present practise appears to be based upon the adaptation of superheating apparatus to standardized forms of boilers and settings, *a leading consideration being the avoidance of disturbance of their accepted designs, or alteration of the accepted relation of boiler parts.* It has thus become very common practise to install superheating surface in some one position in the gas passages, where a more or less convenient space exists in a standard design, without special regard for its full desirability, or for a well adapted relation of the superheating surface to the path of travel, volume, or temperature of the gases. Manifestly, if existing designs of boilers and settings are to be rigidly adhered to, this must be the case, but it would seem that the eventual aim should rather take the direction of a remodeling of the designs of both boiler and setting, in favor of the superheating apparatus, and that the latter should receive a greater consideration than its present very sec-

ondary position in the combination. Merely to place a superheating coil in a certain part of the gas passage of a boiler, and to connect the steam supply to it, is by no means to be regarded as a complete solution of the problem. * * * We may look forward to the time when the present methods of haphazard combinations of fuel, chimneys, grates, boilers, and superheaters, often brought together without any co-relation, and even without any distinct object, will be exchanged for * * * defined combinations of the furnace with superheating generators, developed from the information and experience which has been accumulating about the subject in recent years."—Reginald P. Bolton, in *Superheat and Furnace Relations,* A. S. M.E. Transactions for 1907. While Mr. Bolton's remarks are to the point, little heed has been given them.

523. If a boiler is to be equipped with an efficient superheater the water heating and superheating surfaces should be carefully coördinated to each other, and this cannot be done by inserting into some part of the gas passage of a boiler such superheating surface as there is room for, and thus adding it as an excrescence or afterthought. Yet as most boilers are designed that is the only course possible. If a high superheat is wanted it usually cannot be got, and if repairs are needed they cause extreme trouble because of inaccessibility. For instance, consider the difficulty of installing a superheater of any high capacity between the first and second tube banks of Figs. 101, 102, 117 and 143 and the difficulty of getting at it if leaks should occur, or repairs later be needed.

The Kidwell boiler was designed with full knowledge of these facts, and provision was made for installation of superheaters which are not only always easily accessible, and convenient to repair, but the capacity that can be installed is *far beyond any other type.* A superheat of 300 to 400 deg. as sometimes needed for special processes, can easily be arranged for without placing it in the furnace where the danger of overheating is ever present. Further, the boiler and superheater surface can be adjusted to the proper relation to each other.

524. The above is true because there are two places in the gas passages available for superheater installation. The first is the space between the drying tubes 9 in Fig. 149 and the tube bank below. This will permit of an installation producing a higher degree of superheat than possible with many other boilers, and there is no danger whatever of overheating the superheater tubes under any conditions. Fig. 191 shows a superheater so placed.

525. If a higher superheat than possible with the arrangement above described is wanted, the triangular space between tube banks 5 and 6 in Fig. 149 is available, and the baffles can be so adjusted as to permit the installation very easily. The boiler tube surface can be adjusted to suit the superheater, and either 6, 5, or 4 tubes be used in the lower tube bank, or the upper bank, or any other arrangement necessary, without having to use either drums or tubes which are not standard.

526. If an extra high superheat is needed it can be obtained by installing a superheater in each of the above stated locations, and connecting them in series, consequently purchasers who need extremely high superheats which were previously unobtainable can now have their requirements filled without trouble.

527. It is thus obvious that the Kidwell Two-Flow Ring-Circuit boiler far outstrips all others as to its provision for superheater installation, but there remains another requirement no less important, *but not mentioned because previous designs could not meet it.* This is means of preventing the superheater from dropping in efficiency, and finally overheating and failing, because of deposit on its walls of incrustation and sediment brought in by wet steam. This also the Kidwell boiler prevents, and the life of the superheater is therefore greatly prolonged. For method see Sect. 534.

528. Handling Impure Feed Water. It is becoming more clearly recognized that the function of a boiler is to generate steam, and not to act as a water purifier. In consequence, most large plants use separate means for purifying bad feed water if no other can be obtained. But such equipment does not always remove all of the impurities, and in case of emergencies untreated water may have to be used. In smaller plants purifying systems cannot always be afforded. Again, in places where the feed water is usually excellent, storms and floods may occasionally pollute the supply. It is therefore of supreme importance that a boiler be able to use raw feed water with the least possible chance of developing trouble.

529. This the Kidwell boiler does with high efficiency. Sects. 113 to 115 show the possible quantity and effect of impurities, Sects. 119 and 120 how boiler design influences the place of de-

posit of solids, and Sects. 121 and 122 the features of design necessary to prevent deposit on the tubes over the fire. The Kidwell boiler *complies exactly* with the requirements thus laid down, and its feed entrance is also correct per Sect. 133. The entering feed is quickly mixed with 300 or more times its weight of water at the steam temperature (Sect. 455), hence is quickly brought up to or higher than 302 deg., at which temperature the impurities begin to precipitate or to deposit. As to the latter action this boiler has a feature of advantage over designs like Figs. 102 and 143 as follows:—In these the motion of the water in the rear bank is so slow that the scale forming material which separates out and deposits on the tube walls carries there with it a portion of the precipitates which, *if alone in the water,* would drop solely as sediment. In consequence, the deposit on the tube walls consists of both scale forming material and sediment, hence builds up just that much faster. If, however, the water moves with sufficient speed to sweep these sediments with it they will be carried to the mud drum and dropped there when the water slows up its speed in this drum before passing into the front tube bank. In consequence the Kidwell boiler does not incrust the walls of the rear tubes as rapidly as done by Figs. 102 and 143, and it more efficiently conveys the sediments to the mud drum. Since no steam forms in the rear bank the scale which does deposit there cannot bake hard on the tubes, hence remains porous and soft, so that it can easily be detached by the turbine cleaner. See Sect. 116.

530. Therefore, before the water passes into the tubes over the fire it is so freed of impurities that the danger of deposits occurring on these tubes is but a small fraction of what it is in header types, as proved in Sects. 120, and 250 to 253. Proof:—Owing to an emergency a certain Kidwell boiler had to be operated 5½ months *continuously 24 hours per day,* and at from 200% to 300% of rating. It was expected as a matter of course that at the end of the run a number of tubes would have to be replaced, in accordance with what had been found necessary with other designs of boiler after shorter and less severe runs, as the water was not very good. *When the boiler was shut down and inspected not a pimple, blister, leak, distorted tube or sign of corrosion was found. The tubes were just as straight and sound as on the day the boiler was started.* Compared with other boilers in the plant this one was unusually clean, even after evaporating the tremendous amount of water represented by the above named capacities, for over 5½ months. The contrast between this and other boilers was marked, and this shows that the method of feeding and of handling the impurities in the water works out precisely as it was designed to do, and is in every way a complete success.

The water marks on the drums also showed that in the front and rear drums the water stood at practically identical levels, which is what this boiler is designed to accomplish, and what no other boiler has ever been able to do.

531. Handling Foamy Water. The presence of organic matter or anything which increases the surface tension of the water will cause foaming, as will also salts either found in natural waters such as sodium chloride common in some districts, or introduced during water purification by some processes. See footnote to Sect. 83. Such foaming may be moderate in amount, in which case it merely causes trouble from wet and dirty steam, or it may be so excessive as to lift the water out of the boiler and expose the tubes to burning. In the latter case the only safe plan is to abandon such water. See Sect. 538 for a pertinent illustration.

532. The Kidwell boiler successfully handles water which foams to any degree within permissible use. Foam bubbles are broken by coming into contact with metallic surfaces, hence the baffle 19 in Fig. 149 is provided to break such bubbles before the steam enters tubes 9, and it does so very efficiently. Further, foamy water, and indeed some which does not foam, is prone to the evil habit of "creeping," or climbing up the sides of the drum due to capillarity, especially when the drum walls are coated with a film of dirt which acts like a lamp wick drawing up oil. To prevent this the angle iron seen behind the feed pipe has been provided, and on the other side of the drum the baffle 19 serves the same purpose, hence in the Kidwell boiler this trouble is overcome.

533. In consequence it will be found that unless the feed is so foamy that it is dangerous to use, this boiler will break most of the bubbles before the steam enters the drying tubes, and the latter will evaporate the entrained water and thus superheat the steam somewhat, though not of course to the same degree it will if the water does not foam. For causes and remedies for foaming see footnote, Sect. 83.

534. Separating Scum and Mud from the Steam. If foamy water contains mud, or if the solids are of such specific gravity that they sweep around the water circuit and reach the disengaging surface, the emerging steam bubbles pick up such matter and sweep it into the steam pipe unless means are provided to prevent such action, and such means are not possible in any boiler delivering wet steam at the nozzle. The amount* of such material swept out is far larger than supposed and it causes many expensive troubles. It is this which plugs up steam traps, renders steam unfit for cooking or many processes, fills up steam chests with mud, and causes excessive wear of all rubbing parts of engines which come into contact with steam. When superheaters are installed the consequences are even more serious, since this material fouls the tube walls, rapidly reduces their efficiency, and more rapidly overheats and destroys the tubes. This is a matter not referred to in boiler catalogs, for obvious reasons, yet it is apparent that the elimination of this nuisance is of the utmost importance.

On this point an editorial on *Value of Dry Steam,* in *Power,* Sept. 23, 1912, says:—"There is another advantage to dry steam which is not so often discussed; it does not carry over foreign material from the boiler with it as wet steam does. A case of severe cylinder cutting was traced to the boring out of the boiler tubes and the carrying over by the steam of fine sharp powder which had not been thoroughly cleaned out. When a superheater is used it will soon become scaled up if some 5% of the water is evaporated upon its surface." And it will scale up if *any* water is carried over, though the greater the content of water, the quicker such scaling will occur.

535. The Kidwell boiler is designed to meet this necessary requirement as it does all others. As the steam passes through the drying tubes 9 in Fig. 149 the bubbles are dried out, and the dirt contained in the water is therefore dried out also, and is reduced to condition of minutely divided powder which is conveyed along the tube and delivered into the drum with the steam when it impinges on the plate A, Fig. 163. The steam passes to the collecting pipe B, while the dirt is swept off the plate and falls on the water surface below. There it becomes wet again, and settles as a sludge to the bottom of the drum, whence it is drawn off through drain pipe C.

As evidencing both the necessity and efficiency of this device, it is found that *in some of the mills on Lake Superior where the feed water becomes highly impregnated with foamy matter during storms, the quantity of material blown out of this pipe is not infrequently twice that passed out through the bottom blow off!* The serious consequences of passing such a quantity through superheaters and engines are too evident to operators to need comment.

536. Unless otherwise specified all Kidwell boilers are fitted with such blow out device, and in consequence the steam from these boilers is *clean,* and when superheaters are installed their walls are thus protected, their efficiency is maintained, and their life greatly prolonged.

537. This deficiency is better appreciated in Europe than here, and means are taken to overcome it. "To avoid impurities being carried over into the superheater, a drum is installed between the saturated steam outlet and the superheater, to allow the sediment to settle in the drum by the reduction of the steam velocity."—*Modern European Tendencies in Power Plant Design,* in *Power,* January 10, 1922. See Figs. 115 and 116 for examples. This practise should be taken up in this country, and be insisted upon in connection with every boiler delivering wet and dirty steam, and Chapters III and IV show that such are numerous.

538. Caution as to Feed Water! *Do not under any circumstances whatever venture upon feeding a boiler with water the nature of which is unknown to you!* Have such water tested first by a chemist who understands feed water and is competent to advise you. Failure to do this has led to some frightful disasters. To cite a case, 4 new boilers were installed within 200 ft. of an old plant which they were to replace.

*"I have found that considerably more than half of the dirt in the boiler feed passes over with the steam. In many cases the proportion of the solids in the feed which go out with the steam is 90%, or more. I have compiled considerable information and data on this subject in the way of theoretical figures and actual examples of *enormous amounts of dirt passing out of the boiler with the steam,* and will admit that I was surprised myself, when the amount passing to the steam header showed so high."—O. R. McBride, in *Power,* April 10, 1923, p. 570. For complete confirmation of these statements, and further evidence of the evils of *dirty steam* see letters from Messrs. Andrews, McHugh and Naylor in *Power,* May 22, 1923, page 809.

A new well was driven within 150 ft. of the one already in use. The new boilers were filled with water from the new well without any examination of its quality, though some pressure had been unsuccessfully used to have such examination made. In a few minutes after the new boilers began to steam they ejected nearly their entire water content into the mains, which were wrecked, as was also the engine, one man was killed outright, another fatally wounded, and the front bank of tubes in all 4 boilers were burned to a crisp! The *new* well had tapped a stratum containing over 10 times as much salt as found in sea water! The moral is plain.

539. Provision for Free Expansion. In Fig. 149 drum No. 3 is securely anchored to the frame, while drums marked 1 and 2 and the tube banks connecting them *swing entirely free,* hence expansion is fully provided for. Drum No. 4 is also anchored to the frame, therefore tubes 9 are provided at both ends with generous bends sufficient to take up the expansion. It is to be noted here that the rapid circulation in this boiler protects the structure from sudden temperature changes, which in connection with the construction above described eliminates all expansion troubles. Compare this with Sect. 324 and Figs. 102, 118, 119, and 143.

Efficiency.

We must consider the design as to both Fuel Efficiency (Sects. 106 to 112), and Efficiency of Capital (Sects. 139 and 140).

540. Fuel Efficiency. Consideration of Fig. 47, Sects. 110 to 112, and similar items which affect this efficiency evidence that any statement as to what general fuel efficiency a boiler can develop without taking into account every such factor, is idle and worthless conjecture.

541. But regardless of how these factors vary there are some which dominate all others, and by these the excellence or deficiency of a boiler as to fuel efficiency is to be determined. These are as follows:—

(a) **The Furnace.** The first essential of high fuel efficiency is good combustion. This requires ample furnace volume and height. See Sects. 156 to 174. Illustration:—In a certain plant there are two floors containing boilers and equipment in duplicate except as to furnace volume. On one floor the boilers contain 75% more volume per *rated* HP. than in the other one. The former develops 74% efficiency and the latter 54%. The moral is obvious.

The reason for this is shown in Sects. 157 to 159 and Figs. 50 to 54, in the first 4 of which the curves show the difference in results obtained by varying the amount of combustion space, and the figures at the end of the curves show the number of cu. ft. of furnace volume per sq. ft. of grate. Referring to the solid line curves in Fig. 50, where 2 cu. ft. per sq. ft. of grate were used the best result showed a loss of 16.8%, with 86% excess air and about 9.9% CO_2. When 5 cu. ft. of furnace volume were used the loss was only 8.1%, with 32% of excess air, and 14.2% of CO_2. The other curves show how these percentages vary for different kinds of coal, but they all prove the important fact that the larger the furnace volume, the less *the amount of excess air and the higher the percentage of CO_2, and also that high percentage of CO_2 in a furnace of deficient volume does not necessarily indicate high economy.*

The furnace must also be so arranged as to transmit to the boiler by direct radiation the maximum possible percentage of the heat.

In the *standard* sections of Kidwell boiler the requirements as to furnace volume and height have been provided for to an extent not found in any other design *unless it is set special.* Note "important caution" in Sect. 589.

(b) The gas and water flow must be in correct relation to each other. This condition is almost exactly complied with by the Kidwell boiler, as shown in Sect. 461.

(c) The setting must be tight to prevent gas leaks, and so designed as to cause the minimum loss from heat radiation. For this reason we have devoted more care to working out details of setting than any other boiler builder, and if our specifications are observed the Kidwell boiler will comply perfectly with this requirement.

(d) The water circuit must be free from all throttling. This design meets that requirement. See Sect. 462. Contrast this with *all header types,* and other curved tube types like Figs. 101 and 102, and read Sect. 471.

(e) The quantity of water passing and its speed must both be maximum. This condition is also met, as shown in Sects. 467, 468 and 472.

(f) The water must enter the circuit at the proper point (Sect. 133) and deposit the minimum amount of solids on the tubes over the fire. This requirement is also perfectly observed as shown in Sects. 528 to 536.

(g) The exterior heating surface must be so arranged that it can always be kept clean. This

also is accomplished by the Kidwell boiler, per Sects. 558 and 559.

(h) Priming must be wholly eliminated. It is, in the Kidwell boiler, with any kind of water permissible for use, and *the steam is also superheated,* wherein it stands in a class by itself, as proved in Sects. 513 to 519.

To those who buy on *first cost only* without consideration of what the equipment will do the following will be illuminating. In Sect. 206 we state that economizers usually will pay *provided they are properly proportioned.* Those who refuse to pay the slight extra cost necessary to get a high grade boiler often do not hesitate at paying for an economizer which, because of *improper proportioning,* yields but a small return. Example:—Tests on a prominent plant as published in *Mechanical Engineering,* October, 1921, show for the economizers an average heat recovery of only 4.1%. But as proved in Sects. 96 and 97 the *loss due to wet steam is far higher than this,* and such loss the Kidwell boiler overcomes completely, hence the slight difference between the price of this boiler and one delivering wet steam yields a greater return than a much larger sum invested in economizers not properly proportioned to the boiler. *Even if the proportions are made right the Kidwell boiler is still to be preferred,* since it can with ease develop the high ratings necessary to make an economizer pay as it should. See Sects. 210 and 211.

(i) The gas courses must be long so that the maximum percentage of heat is extracted (Sect. 291), and so arranged that the heating surface is not short circuited. This requirement is also met. By comparison with, say Fig. 102, it will be seen that in the Kidwell boiler the gases travel a considerably greater distance before reaching the damper, without any such disadvantages as described in Sects. 316 and 317. The gas passes are so designed that there is no short circuiting, and the baffles are so constructed that they remain tight.

(j) The efficiency should not fall off rapidly because of scale deposits during a run, as described in Sects. 110 to 112. This is met as shown in (f) above.

(k) There must be no exposed surfaces to act as condensers. In the Kidwell boiler all parts are housed in by the setting except the drum heads, and they can be cased over with insulating covering. See Sects. 201 to 207 for devices which do not comply with this very important requirement.

(l) The efficiency must not drop rapidly as the rating increases. In this the Kidwell boiler stands alone, because of the rapidity of its circulation. See Sects. 37 to 41 and Figs. 4 and 5 which prove this. Note that this boiler has a speed of circulation far in excess of the design which gave line A in these figures, hence under identical conditions its fuel efficiency would be higher than shown by that line.

(m) Tube losses must be a minimum, as every overheated tube represents a fuel loss, per Sect. 43. In this requirement the Kidwell boiler also stands in a class of its own as shown in Sects. 147 and 476 to 482.

(n) Fluctuation of the water line must be obviated for reasons given in Sect. 511. In this respect the Kidwell boiler again stands alone, since *it is the only design known in which the water in parallel drums remains at the same level and does not fluctuate with variations of load,* as proved in Sects. 504 to 507 and 530.

542. It follows that as to fuel efficiency the Kidwell boiler meets every requirement and fulfills every demand, and that if all factors are taken into account so that the finding is based upon *which boiler can with any given engine produce the maximum power with the least fuel,* it surpasses all other boilers, and this is the only criterion upon which a just judgment can be formed, because it is the only way in which the *quality of steam* produced by the boiler can show its effect on the final *efficiency as to MONEY.*

Efficiency of Capital.

543. Sect. 140 shows that this is the most important of all efficiencies pertaining to boilers, hence it deserves the fullest consideration. The first item is *safety.* To get a clear idea on this it is necessary to correct a prevalent erroneous impression as to "safety boilers."

544. Meaning of "Safety Boiler." This term is so widely used that many interpret it to mean *a boiler which cannot explode,* and the wording of some boiler literature rather fosters that notion. Therefore, it must be understood at once that *there is not now and never will be such a thing as a boiler which will not explode!* Further, boilers explode for just one reason,—the pressure is sufficient to rupture the weakest part,—and it is evident that no matter how strongly such vessel may be built it is possible to apply to it a pressure which will rupture it somewhere. According to the nature of the design the rupture may be extensive, or trivial. In the first

case the structure is more or less completely wrecked, with serious consequences not only to operators, but to buildings and adjoining property. Thus, the explosion of a relatively small tubular boiler may cause a most destructive wreck of large magnitude.

545. The principle of the water tube boiler is to separate the water volume into many subdivisions, and to place these parts so that those exposed to high temperature, deterioration owing to action of heat, erosion of fast moving water, and general wear and tear, are small in size, so that if such a part fails the rupture will be small, hence permit only a gradual escape of the water and steam and thus prevent a serious wreck, and permit the defective part to be renewed at small expense. In other words, the principle underlying all water tube boiler design is so to arrange the parts *that if an explosion does occur, it will be local instead of general!* It is in this sense, and only in such sense, that any boiler can be designated as a "safety boiler."

546. Such a boiler, if subjected to excessive pressure will rupture in some part, and that must be understood. But, if properly designed, and operated with due care, such boiler will be immune from explosion, hence in that sense is a safety boiler. Hutton, *Steam Boiler Construction,* p. 558, says:—"The explosion of a steam boiler is not an accident and is always preventable, because it proceeds from a cause which might have been foreseen, the defect could have been remedied, and the explosion prevented." Therefore, if *any boiler, water tube or otherwise,* be allowed to accumulate incrustation on the parts subjected to high temperature, weakened by corrosion of the metal, or overstrained because of stuck safety valves, or operated during periods of low water, or otherwise abused or neglected it will fail in some part, hence explode.

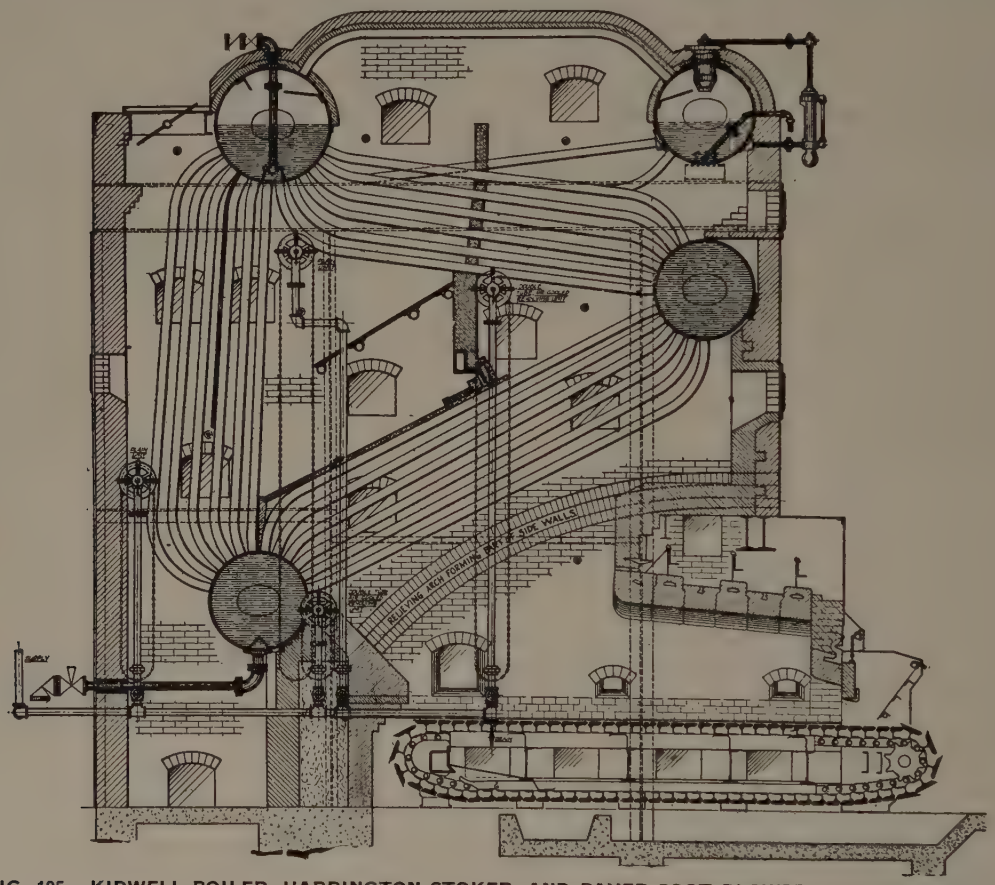


FIG. 195. KIDWELL BOILER, HARRINGTON STOKER, AND BAYER SOOT BLOWER. ALSO SEE PAGE 6

547. But even if operated with utmost care a boiler may explode because of incorrect design, poor material and imperfect workmanship, and it is these features which must be scrutinized.

One of the most fruitful sources of failures is complication in design, and multitudes of parts to be opened, closed, and maintained. As to this Hutton, p. 248, says:—"In a steam boiler, *as in all things mechanical,* the supreme *excellence is simplicity. The risk of break down increases with complication.* As it is generally necessary frequently to renew some portions of boilers of complicated structure, they are more expensive to maintain than those of simple construction, and they are also more liable to accidents and injury from neglect. *These disadvantages cannot be balanced by even the attainment of the highest possible economy in the generation of steam!* The most economical steam boiler is that which is safe, simple, and durable, and evaporates the largest quantity of water to dry steam, with the utilization of the greatest percentage of the heat developed by the combustion of the fuel." As confirming this see *Boiler Explosions* in *Power,* Nov. 7, 1916, and note the great percentage of those which occurred in boilers with headers and other numerous parts of complicated shape.

548. Safety Features of the Kidwell Boiler. Within the meaning of Sect. 545 this is preeminently a safety boiler. Simplicity, as demanded by Hutton, is obtained to an unexcelled degree. The manheads in the drums are the only parts to be opened up and closed during inspection and cleaning. The multitude of hand holes, caps, headers, stay bolts, tie rods, gussets, mud pans, throat bridges, parts of complicated shape and uncertain strength, temporary joints which cause trouble from leaking, and crooked passages which collect scale deposits (see Sects. 145 and 146) are all eliminated. The pressure vessel consists solely of drums and tubes every part of the interior of which is accessible for cleaning, and every joint and rivet of which are accessible and visible. These elements are all cylindrical or spherical in shape, and these are the only shapes which under pressure do not distort from their original form, and whose dimensions can be *accurately* computed. In contrast, see Figs. 101 and 126, and Sects. 336 to 338.

549. The pressure vessel is constructed wholly of forged or wrought steel or ductile electric cast steel, all proportioned to comply with or exceed the requirements of the various codes as stated in Sect. 399. Add to this that the fittings are of corresponding grade as stated in Sect. 418, and the result is a boiler as safe as human skill and present state of the metallurgical and mechanical arts can produce.

550. Contrast with Other Designs. The extent to which the Kidwell boiler surpasses others with headers, large flat sheets, etc., as to simplicity is so evident that for brevity we will pass this by and next consider the difference as to the multitude of openings in header types, *each of which is a source of weakness* as well as of leaks and other troubles.

551. To illustrate, take Fig. 35. This boiler has 504 tubes, and the distance from floor line to center of rear header is about 16 feet, and of front header 21 feet, a mean of 18½ feet. Accordingly, there will be in the headers 1008 hand holes to be opened in addition to those in the mud drum and the manholes. Each hand hole cover contains 4 or more separate pieces, so assume 4 as the minimum. This means that 1008 holes are to be opened up, their faces carefully cleaned, bearings machined off if found in bad shape, and 4032 separate cap pieces besides those in mud drum, must be handled and cleaned up, and the cap seats smoothed off.* These cap parts weigh on an average 10 lbs. per opening, hence the work to be done in merely getting them to the floor will be $1008 \times 10 \times 18\frac{1}{2} = 81{,}648$ foot-pounds, or 40.8 foot-tons! An equal amount must be expended when raising them up again, and probably many times that amount when handling the parts, taking them to a bench vise when doing any fitting, cleaning, etc. The necessity for cleaning the various parts will become evident upon inspecting the caps before removal. These are often completely covered with white scale or festoons of material in fine shreds like moss, due to leaks. See Sect. 146. The removal of such material is of course necessary, and it is a long, tedious and expensive job. Yet the great inducement held out to buyers as a compensation for all this expense and time lost, is *superior fuel efficiency.* As to how that claim proved out as to fact, see line D, Fig. 4, and Sects. 222 to 224 which show the performance of the identical boiler above used for this illustration.

552. To complete the case, assume this design needed gaskets for the hand holes, then figure the cost of replacing over 1000 of them, as against four manhole gaskets in the Kidwell boiler which are exactly offset by similar man-

*See footnote to Sect. 144.

hole gaskets needed by the other designs. See Sects. 237 to 239.

553. The next safety consideration is the relative liability of tube ruptures. This depends on the relative speed of circulation, the way the heat is applied to the steam generating tubes, and the method of depositing solids, in both of which the Kidwell boiler is superior to others, as proved by Sects. 119 to 122, 147, 249 to 255, and 476 to 482. Here it is to be noted that while an exploded tube may not wreck the boiler or building, it can kill the operator just as dead as if the whole plant were blown up.

554. Capacity. Safety being assumed, the next important question is "If I buy this boiler what output can it produce?" This depends upon speed of circulation and proper arrangement of the steam generating surface with respect to the furnace heat and gas flow. In these particulars the Kidwell boiler not only surpasses others, but goes far beyond them to a degree which puts it into a class of its own, as shown in Sects. 461 and 476 to 482, which also prove that it not only has superior capacity, but *increased insurance against burning of tubes when developing that capacity.*

555. Cost of Maintenance and Repairs. Repairs may be needed by both the setting, and the pressure vessel. The former is guarded against in the Kidwell boiler as shown in Sects. 423 and 541(c). The liability of repairs to the pressure vessel is inversely proportional to the number and complication of parts (Sect. 547), and the frequency of tube replacements and cost of making them (Sects. 147 to 155, and 249 to 255). A feature of great importance for the protection of the buyer, especially in plants located far from the point of manufacture, is that *the number of possible repair parts which can be obtained only of the original manufacturer* should be the fewest possible. For an illuminating example of this see the second paragraph of Sect. 568, and Sects. 241 and 242.

556. In the Kidwell boiler *there is no such part whatever!* The only part likely ever to fail is a tube, and any fair mechanic can bend a tube to fit the boiler. See Sects. 154 and 155.

557. Facilities for and Cost of Cleaning. Here we must consider cleaning both the exterior and the interior of the heating surface.

558. Cleaning the Exterior. As shown in Sects. 435 and 436 ample access doors are provided, and the interior space is so arranged that a man can get in and work with a facility rarely possible in other designs. The heating surface can be blown off by steam or air lance, and be kept clean and efficient.

559. Soot Blowers. The modern way to remove soot from boilers is to install a good mechanical steam soot blower. There are some reliable designs on the market and they will soon pay for themselves. Care should be taken to select one which is durable, and contains sufficient blower elements to sweep the entire surface. Hand blowing is shirked by operatives, while if a good mechanical blower is installed it will usually be used properly, because by so doing the saving effected reduces the amount of fuel the fireman has to handle.

The Kidwell boiler is perfectly adapted to installation of such blowers, as shown in Figs. 150, 151, 178 and 195.

560. Cleaning the Interior. This is done as explained in Sects. 141 to 143, from which it is clear that the Kidwell boiler is far in the lead of all others except some curved tube types like Figs. 102 and 143, and that to a slight degree it exceeds these for reason given in Sect. 529.

561. Financial Aspect of the Time Required for Cleaning. This is a most important matter and failure to realize it results in large money loss and increase in investment required. *A boiler is worthless as a money earner except when it is generating steam.* While it is idle, the piping connected to it, ground upon which it stands, buildings over it, and auxiliaries serving it are also idle, *though interest on the investment keeps right on accumulating!*

562. Consider the case quoted in Sects. 550 and 551, and it shows that a Kidwell boiler can be opened, cleaned, closed and fired up in less time than needed to handle such a multitude of caps, hence it is apparent why header types require about 4 times as long to *clean thoroughly* as the Kidwell boiler does. See Weaver's statement in Sect. 251. In consequence of this item alone it will work out that, according to the amount of impurities in the feed and the frequency of cleaning required, *for the same steam output the capacity of header and some other types which must be installed will be 5% to 15% greater than the capacity of Kidwell boilers necessary to do the same work!* This does not take into account the fact that the Kidwell boiler can operate at far higher ratings than the others, so that a smaller installation of

them is needed to begin with. Now to that fact add another of vital importance, namely that the time lost by other types due to more frequent tube failures (Sects. 147 and 249 to 255) and for replacing such tubes (Sect. 153) is entirely disproportionate to what is lost by the Kidwell boiler, and the final summation of these factors will enable investors better to appreciate what they will get in return for their money.

653. Reliability as to Continuous Operation. Section 25(i) defines what is necessary as to this item, and from the foregoing facts it is clear that the Kidwell boiler exceeds others as to this requirement. In short, it not only delivers more output than others, but does so during more hours per annum than the others, hence exceeds them both as to quality and quantity of performance and output.

564. Ruggedness in Operation. This really belongs to the preceding sections, but its importance justified separate mention. The ideal result would be to produce a "fool-proof" boiler, but since that is impossible the next best thing is to produce one which will function properly with the least "nursing" and fixity of attention.

565. The first requisite for this is ample water endurance surface (Sect. 78) to minimize the danger of low water. Observe the difference between Figs. 38 and 39. Herein lies the reason for failure of numerous coil boilers. Notice the deficiency of Figs. 68, 102, 120, 121, 138, 142, 143, etc., in this respect. Now assuming that a design has sufficient *apparent* water endurance surface, the question is whether it has ample *real* endurance surface, and whether such surface steadily decreases as the load increases. See Figs. 105, 142, and 143 to illustrate both of these items, and any longitudinal drum designs to illustrate the latter. Then read account of *San Diego* explosion referred to in Sect. 235(b).

566. As shown in Sects. 509 and 510 the Kidwell boiler not only has ample water endurance surface, *but maintains it unchanged regardless of variations of load.*

Read Sects. 304 to 310, and consider the liability of a slug of water being pulled into the steam pipe because of slight inattention as to keeping the water line precisely where it should be. Consider also the probability of leaks developing because of failure of some of a multitude of joints. Read Hutton's statement in Sect. 547, then note the case cited in Sect. 551 and the further information in Sects. 145 and 146, and check by referring to Figs. 18 to 30, 35, 68, 75, 77, and sundry others given herein.

The Kidwell boiler eliminates all danger of trouble from either of these sources.

567. Liability of Corrosion and Pitting. Improper feeding will cause this as shown in Sect. 137. But another cause inseparable from many designs is extremely irregular water passages in the corners of which the water becomes stagnant and causes corrosion or pitting. It has even been found that trouble of this sort develops

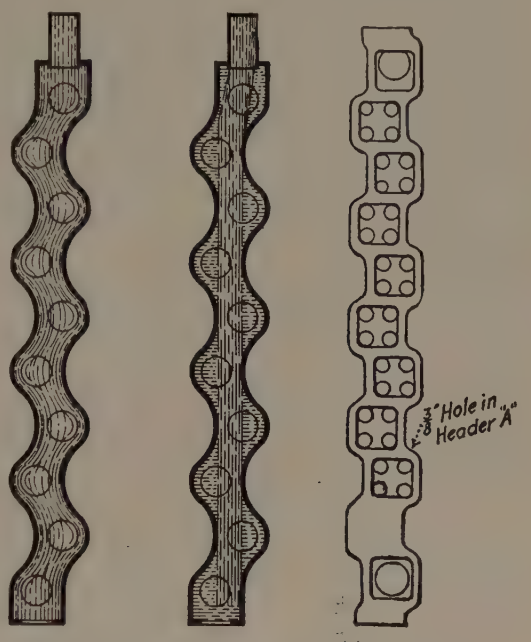


FIG. 196 FIG. 197 FIG. 198
ILLUSTRATING CORROSION IN HEADERS

in forged steel sinuous headers though one would assume that from their excessive throttling of the circulation the water would be compelled to sweep the entire surface as indicated in Fig. 196, yet apparently the corners are not so swept, and the flow approximates Fig. 197. In consequence, it has been found that corrosion occurs in the corners. See *Mechanical Engineering,* September, 1921, p. 599, for a remarkable photograph showing this.

568. It also frequently occurs between the headers on the outside. Fig. 198 shows a case from the U. S. S. Nebraska as reported in *The Boiler Maker,* August, 1915, p. 258, and the account therein given of the enormous expense

incurred in making the repairs necessary to proceed to port will be illuminating as illustrating Sects. 152, 153, and 555.

In the Kidwell boiler there are no such crooked passages and dead water spaces, hence it is free from this source of trouble. To guard against corrosion of the exterior of the drum heads such as appeared to be responsible for the explosions at Mobile and Marion as cited in Sect. 430 provision is made for inspection of all drum heads as in Figs. 169 to 172, in which respect the Kidwell boiler once again is in a class by itself.

Corrosion also results from improper arrangement of water circuit, and wrong disposition of heating surface, as shown in Sects. 265 to 471. It also occurs for reasons given in Sect. 244.

569. Fuel Economy. This has been fully covered in Sect. 541.

570. Adaptability to Wide Range of Conditions. In this respect the Kidwell boiler stands preëminent. As shown in Sects. 375 and 376 it is impossible to produce any one design that is best for every conceivable purpose. The Kidwell boiler is designed to meet the requirements of power plants, and within that field it can comply with every demand, and fulfill every requirement, regardless of whether the load be steady, fluctuating, or intermittent; the pressure medium or very high; the steam to be used directly or first passed through a superheater, and the feed water varying from excellent to the poorest permissible to use. In capacity it exceeds others so that it produces steam at a lower initial cost *per unit of output* than any other.

571. Its furnace is correctly designed both as to height and volume, and can be fitted with any stoker known, and adapted to burn any and every fuel in use. Either vertical, or overhung fronts, if necessary for certain stokers or fuels, can be furnished. For oil fuel an arrangement and volume of furnace impracticable in other types can be provided without any change from our standard designs of supporting framework. See Fig. 192 and Sects. 166 and 167.

572. Waste Heat Installations. The Kidwell boiler is excellently adapted to this service, and for certain requirements peculiar to some industries it is superior to any other, as for instance, in installations for utilizing waste heat from copper matte furnaces. The gases from such furnaces will not attack the metal of the boiler *so long as they are dry,* but if a leak occurs sulphuric acid in large quantity is formed, and the boiler is quickly destroyed. For that reason boilers containing the minimum possible number of joints are necessary, and this bars out all designs with hand holes and caps if trouble is to be avoided. As being the most available design at the time such heat utilization was begun the boiler shown in Fig. 102 was selected by this writer, and it did good work within certain limits. The main objection to it was that with the baffle arrangement as shown, the draft loss was such as either to reduce the furnace output, or require all baffles to be omitted so that the gas swept the heating surface very inefficiently. The latter arrangement was used, and even operating under such inefficient conditions plants of this kind have produced a *saving equal to their total cost in less than one year!*

With its superior design the Kidwell boiler can be so provided with baffles for such work as to permit a far more efficient utilization of the heating surface, yet not cause draft trouble. Further, this arrangement will permit efficient separating and deposit of the flue dust.

573. The Cement Industry presents a wide field of usefulness for waste heat boilers, and the number of such installations is rapidly increasing. Development of this field has been retarded owing to lack of a boiler which perfectly meets the conditions, so that many existing installations have proved unsatisfactory. The quantity of dust in the gas quickly bridges the spaces between tubes, particularly if the latter are staggered. This chokes the gas flow and renders the heating surface inoperative, and the removal of such deposit is in some cases impossible, and in the others it is slow, tedious and too expensive to be satisfactory.

The Kidwell boiler obviates every such difficulty and meets the requirements to the letter. Its tubes are not staggered, but parallel as proved to be best by 50 years of experience with economizers. See Fig. 159. For cement kiln work the tube spacing is such that bridging these spaces with dust is impossible, hence most of the fines settle into a chamber below from which they can be removed by conveyor. Further, the tube banks are accessible, and a "rattle bar" or rod to which a brush is attached can be passed between the rows of tubes, and sweep their surface clean if such is ever desired.

The main difficulty with previous boiler designs is that the gas enters at the bottom, so

that the fines dropped into a pit below are of a temperature too high to permit use of a conveyor. The fines swept along with the gas *have to be carried upward,* hence impede the gas flow, and settle thickly on the tubes, especially if they are horizontal and staggered.

Fig. 199 shows how this is obviated in the Kidwell boiler. By reason of its design the gas enters through the front and near the top, then

Of the small quantity of fines swept along by the gas, a portion will settle on the tubes from which it is easily blown by a hand operated steam or air lance. The angle of the tubes is such that the amount of material so deposited is small. The remainder passes to the exhaust fan, and here two additional improvements are introduced. The gases before entering the fan pass *perpendicularly downward* into a large expan-

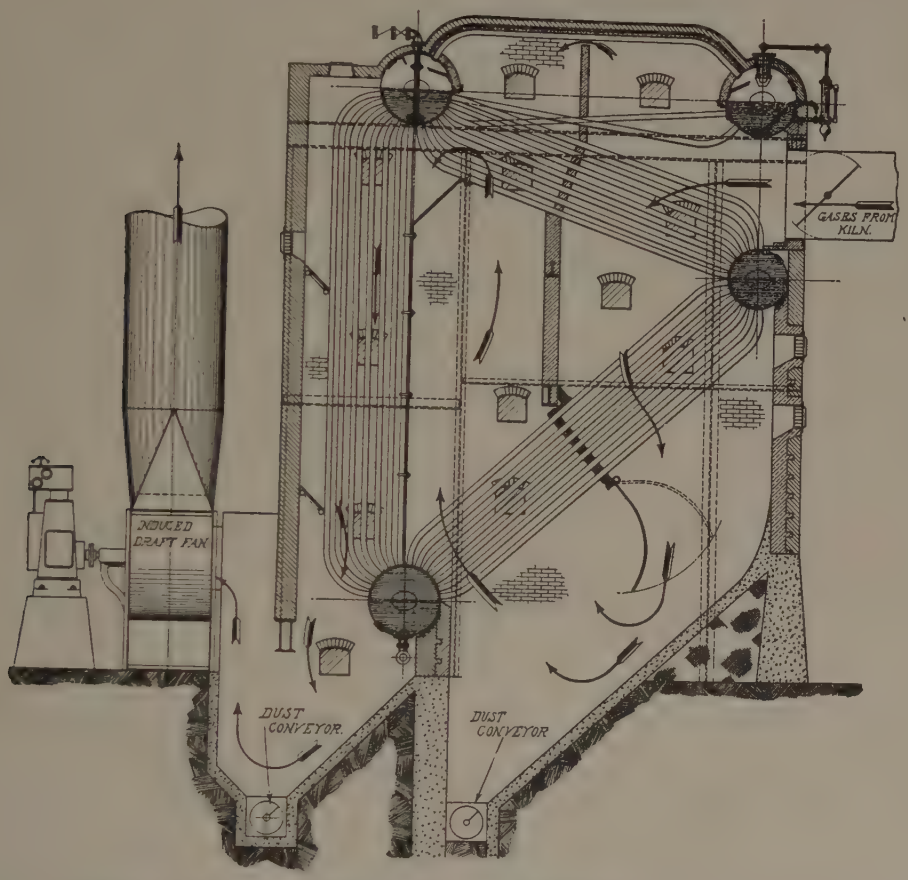


FIG. 199. KIDWELL BOILER AND DRAFT APPARATUS ARRANGED FOR UTILIZING WASTE HEAT FROM CEMENT KILNS

flows downward. Gas and fines then travel together and the velocity projects the latter into the pit below, which is so designed as to deliver them to the conveyor or hopper. Thus not only is the percentage of fines extracted from the gas far greater than possible with any other boiler, but as the gas and fines both sweep over the heating surface the *temperature of both is reduced,* so that the solids as finally deposited are not too hot to be handled by a conveyor.

sion space which slows up their speed so that more fines are dropped to a pit below, hence only a small quantity of fines reach the fan. Means are provided whereby these are thrown by centrifugal force against the outer casing of the fan, and are then piped back into the settling chamber under the boiler, and thus flow into the conveyor below.

Finally, to overcome the trouble of rapid settling of dust on the tubes due to stagnation when

but little gas is flowing in from the kilns, means are provided whereby part of the gas delivered to the fan is returned to the inlet duct and added to that delivered from the kilns, so that the combined volume of these two always cause a sufficient gas velocity through the boiler to prevent stagnation.

574. For all other waste heat installations this boiler is well suited, and we will be pleased to furnish information necessary for any case which may be submitted to us.

575. Burning Refuse Fuels. The furnace can be easily adapted to burning anything which is combustible. Culm and similar material formerly considered worthless is now burned with perfect success either on certain stokers, or by powdered fuel apparatus. Coke breeze, a material difficult to burn and formerly rejected as worthless as fuel, is burned with excellent results. See Sects. 637 and 638. None except a boiler with accelerated circulation should be used for such purpose, as the furnace temperature may reach 3200 deg., but a combination of Kidwell boiler and forced draft chain grate stoker has operated with such fuel for 6 months at 200% to 300% of rating continuously, without a moment's stop even for cleaning, with entire satisfaction and no trouble whatsoever.

576. For saw mill refuse, saw dust, hogged fuel, etc., large furnace volume and grate surface are absolutely essential, hence the Kidwell boiler is particularly adapted to burning these fuels. This Company has designs capable of burning such fuels containing 50% to 60% of water, and operating the boiler at from 150% to 200% of rating, or more. We will be pleased to correspond with clients, and submit proposals to meet their requirements.

577. Space Occupied. The Kidwell boiler is economical of space, and is made in a sufficient number of sections to meet varying requirements as to width, depth and height provided the latter is sufficient to permit the necessary furnace height and volume as set forth in Sects. 156 to 170, and 541(a).

578. An important item, often not realized until too late, is the space which is required for renewing tubes. A prominent maker of header types states that the space necessary in front of such boiler for pulling is one foot greater than the tube length. Thus for 18-ft. tubes a minimum space of 19 feet must be left in front of the boiler. Where oil or gas is used such space represents pure waste, as 10 ft. clear is a liberal allowance for all firing equipment, and we have seen plants operating with entire success, when burning oil, with considerably less space. Even under such conditions there is ample space for replacing tubes in a Kidwell boiler.

579. By reason of the far superior overload capacity of this design over any other, more power *as to actual steam output* can be installed in a given cubic volume than any other. This is true even though with designs of the general arrangement of Fig. 68 it is possible to crowd a *large amount of heating surface* into a small space, but heating surface and steam output are not equivalent things, as shown in Sects. 227, 234, 235, and 479 to 483. It is not only a question of causing a certain heating surface to generate steam, but it is more essential to get that steam away as fast as it is formed, otherwise the tubes overheat. See Sects. 31 to 43 and 249 to 255. The size of the up-comer nipple governs that, and when its capacity is reached, disaster follows any attempt to exceed it. Analogy:—A stack of any given dimensions can convey a certain amount of gas, hence develop a certain boiler capacity. Now, if such stack be overloaded by *connecting additional boilers to it*, not only will there be no increase in the quantity of steam generated, *but an actual decrease*, since the efficiency of combustion will be greatly impaired, as the fuel will be merely stewed or distilled instead of being *burned*. "The strength of a chain is that of its weakest link." The same is true of boilers with throttled up-comers.

580. The new principle by which the Kidwell Two-Flow Ring-Circuit boiler secures its most marked superiority of operation over others is so flexible that it can be applied in many ways. This Company has worked out other arrangements than herein shown, which may be applicable under conditions which may later arise.

581. First Cost. This item is the one at which buyers often look first, but as to which more mistakes are made than any other, and it is precisely because of this fact that the market is filled with "designs" which, if dissected in accordance with the proved technical facts and principles summarized in Sects. 381 to 385 will prove unattractive if offered gratis. See Sects. 98 and 99. No apology is therefore needed for a very full discussion of this vital subject.

582. The initial purchase price of a boiler is of *no consequence whatever* in comparison with

obtaining the correct answer to the question stated in Sect. 25(1):—"What boiler, from the day I buy it until it goes into the scrap pile, will return to me the largest earning on every dollar I spend in buying, installing, operating, and maintaining it and the other equipment I have to install as essential to its operation?" Consequently, it is futile to consider purchase price apart from *final result cost extending over the life of the boiler.*

583. When comparing boiler quotations the first item to consider is "Just what does this price include?" Such is necessary *as it is invariably found that one proposition includes many things which the others do not,* hence credit for these must be given, since otherwise the purchaser must pay extra for them. This item is frequently, in fact *usually, overlooked.* Example:—In a certain case a specification was approved and the business offered if the proposer would make a reduction of $900.00 to meet a competitor's price. Upon this being refused the order was placed with the latter. It was soon found that the boilers to be furnished would not pass inspection so others had to be substituted at the extra expense of the seller.

It then developed that the accepted proposition did not include many items contained in the other, and the value of them, which the purchaser had to supply, greatly exceeded $900.00, besides which unexpected changes had to be made to accommodate the design furnished. In the end the purchaser wound up with a botched plant, a boiler which proved inferior to the other, and an *additional unexpected outlay of $5000.00 above the amount in the proposal which was rejected!* A checking of a design item by item with Sects. 381 to 386 will protect the buyer against such error.

584. Therefore, the next item to consider as to first cost is, not merely what *some one part,* like the boiler, will cost, but the total cost of the completed installation, ready to make steam. Here every item named in Sect. 140, and others involved also, must be taken into account. *By so doing it will invariably develop that the boiler offered at the lowest price is never the cheapest, and often the most expensive!* For example, by proper boiler selection, the saving which can be made in the stoker, feed apparatus, breeching, stack, ground, buildings, bunkers, etc., will not only overbalance the difference between the quotation on a good boiler and a poor one, but effect a large saving besides. See Azbe's statement in Sect. 593 which confirms this.

585. The next item is proper consideration of what this equipment will return to the buyer during the next 25 or 30 years. A boiler is not like an overcoat which can quickly be discarded and replaced if it does not please when delivered. Either its deficiencies and annoyances must be tolerated, and daily paid for as a penalty for making a poor purchase, else it must be replaced. This involves the triple expense of removal, repurchase and installation of a suitable design, and suspension of operation while such work is in progress. The sum thus required is so great that disappointed buyers usually have to bear with what they have. Therefore "Look before you leap" is a good maxim to follow here. As to the Kidwell boiler the preceding discussion in general and the items in Sect. 583 forcibly apply.

586. Consider the One Item of Fuel. Both its cost and the difficulty of obtaining it are daily increasing. What will these conditions be during the period over which the proposed plant will operate? Judging from the past all probability suggests an increase in costs. Against this, figure the items from Sects. 541 and 542, and they indicate the only proper course to follow.

587. That a boiler built to secure fuel economy necessarily costs more than one which is wasteful is easily shown. Sundry boilers with short gas courses (see Sect. 291) are offered at low prices. But it is found that their exit gases are of high temperature. To show why, refer to Sect. 451, and note the relative percentage of heat absorbed by the different passes of the boiler. Suppose we omit the last 35% of heating surface in the Kidwell boiler, then *what remains* will be a fairly good sample of a boiler with insufficient length of gas passes, and its capacity will fall short of the full arrangement only about 7.31%, but its fuel efficiency will be reduced about 9½%. Obviously, the higher the rating at which the boiler is to be operated the more objectionable such short gas courses will be. By referring to Sects. 98 and 99 in which a difference of only 5% is capitalized it will appear that any boiler with short gas passes is too expensive to accept gratis, and has no value otherwise than as junk.

588. It is this reason which compels the use of economizers, high steam pressures, superheaters, automatic cut-off, and multiple expan-

sion engines and turbines. These are all used just to save that last 4% to 15% or more which otherwise would be wasted. For the same reason buddles, Wilfley tables, oil flotation apparatus, etc., are used in stamp mills and ore dressing plants. They save the last few per cent otherwise lost in the slimes. Yet even such plants frequently tolerate a large loss of heat up the stack because the boiler plant has not received the same degree of consideration as the remainder of the equipment.

589. Important Caution. The pressure vessel or "kettle" *alone* does not constitute a "boiler." See Sect. 381. This is constantly overlooked. If the furnace volume is insufficient the combustion will be incomplete. *This will produce high temperature of exit gases no matter how perfect the design and proportion of the pressure vessel may be!* If the coal contains a high percentage of volatile matter, flame will continue far beyond the furnace and through the gas passes, hence the breeching temperature will be too high. The reason is shown in Sects. 153 to 169 and others.

590. The Kidwell Two-Flow Ring-Circuit Boiler Not a "Competition" Design. This must be clearly understood. It is an instrument of engineering service designed wholly for production of economic results. Its purpose is to economize in operating costs for the 25 years or more during which it is in service, rather than on *first cost.* The two requirements are wholly irreconcilable. See Sect. 593.

The reason why shrewd engineers buy the articles named in the preceding section is to save money by reducing operating costs. An economizer is a good investment, hence purchasers gladly pay for one, yet no economizer will save an amount equal to the difference between a Kidwell boiler and another which is poor in general design, and produces wet steam. But the difference between the cost of such deficient boiler and the Kidwell boiler is less than the cost of an economizer. The same applies to superheaters and other appliances whose purchase is profitable and justifiable. But there is even more reason for buying a Kidwell boiler in preference to an inferior design.

591. The slight difference in cost is due to the difference in the articles themselves. For the same reason that a Corliss, unaflow, or other high grade engine costs more than a plain slide valve design, a Kidwell boiler costs more to build than *others which cannot do the same work.* Considered merely as hardware this boiler therefore cannot possibly compete with many others, and makes no pretension of so doing! Considered as a tool for production of steam, the preceding exposition of its capabilities proves that *it gives larger returns on the investment than any other, and that is just what it is intended to do and why it was placed on the market.* It is therefore intended to interest engineers who seek *results first,* and investors whose aim is *to buy results where they can be got the cheapest* rather than to invert the process and buy machinery at the lowest cost without reference to what output it will deliver. It is designed in accordance with the principle laid down by Mr. Willard, and quoted in Sect. 279.

592. Yet it is to be observed here that the Kidwell boiler is reasonable in first cost, if considered with reference to *what is included in its sale price.* A study of these pages will prove that as to Efficiency of Capital it is so superior that it would be a preferable purchase if held at double or triple the price asked for it. There is no escape from this conclusion.

593. It is impossible to sum up this matter better than already done by that keen analyst of boiler operation, Mr. Victor J. Azbe in *Boiler Plant Efficiency,* A. S. M. E. Transactions, 1921, thus:—"A new up-to-date installation designed for high capacity and efficiency does not cost *initially much more, if any more, per HP. developed than the ordinary run of wasteful plants.* The subsequent operation of such a plant will be cheaper and so the fuel saving is almost entirely a net saving. It is certainly better to *pay twice the amount per rated HP. for an installation having 100% overload capacity at high efficiency, and economical in labor, than only half this amount for a wasteful installation capable only of an output around rating.* Nowhere is there such an opportunity for good return on the investment as in the boiler house, where a few dollars properly applied can perform wonders." It would be well if some society for the elimination of unwise purchasing would have this statement reproduced on bronze tablets and place one copy of it on the desk of every power plant designer and machinery purchaser!

594. Objection Proposed and Answered. The Kidwell boiler is the latest in the field, and as fully set forth in this book it embodies in its design features in advance of any of its predecessors, in consequence of which it is superior to

them all as an investment. It received instant recognition, has been approved and commended by some of the best engineers of the age, and received a welcome never before given to any other design. It is therefore destined to displace others whenever correct technical principles are understood and purchases are made in accordance therewith.

595. The Kidwell Two-Flow Ring-Circuit Boiler *in its present final and perfected form* has not been in the market for a long time. But as to the essentials of its main water and steam circuit, however, *it has been in use longer than any other water tube boiler now on the market,* since it began with Gurney before 1826, as shown in Sect. 346, etc., and the correctness of its principle was then clearly proved. This was more fully elaborated by Bonus, Sect. 349, by Linton, Fig. 145, and by others who appropriated the labors of these pioneers. The boilers so produced were defective in the particulars described in Sects. 353 to 362. To develop the design so as to eliminate these deficiencies it was necessary to add the features herein proved to be necessary, and this has been completely accomplished in the Kidwell boiler in the manner explained in Sects. 396 and 503 to 508.

596. A Properly Qualified Engineer formulates what is to be done, then designs the means to do it. Before the structure is built the designer knows substantially what it will do. It is precisely thus with the Kidwell boiler. *Its design was not a matter of groping or guessing,* but of correct application of proved technical principles and the structure functioned precisely as it was planned to do. As the new features necessary were those pertaining purely to the flow of water, steam and heat, it follows that *if when the design was tested it worked correctly, for one day or even one hour, it would so work for all time,* as it has since done and ever will.

597. As to the mechanical construction, consider Fig. 102 which has been in successful use for over 30 years, and that the Kidwell boiler has simply *improved on that construction,* consequently marks an advance.

598. Finally, the new and improved features of the Kidwell boiler in consequence of which it excels others are due solely to the exhaustive study by which *what really occurs inside a boiler* has been ascertained, and the application of correct scientific knowledge to the task of so asembling previously proved principles, methods and constructions that the resulting aggregation of members introduced into boiler design an entirely new principle whose perfect action follows in harmony with the immutable laws of physics, and in consequence of which previous deficiencies are overcome, and the object sought is fully accomplished. When this was done the design was at once standardized to a degree never before undertaken. In other words this Company *at its own expense* did all the pioneer work rather than follow the usual course in which the buyer is not infrequently used as an instrument of experimentation.

599. Resume and Conclusion. It thus appears that the main circuit of the Kidwell Two-Flow Ring-Circuit boiler operates on a principle which was proved to be the only correct one, *and that too nearly a century ago!,* that such discovery antedated the other designs on the market today, which are partly or wholly wrong as to their theory of circulation, and that such error is inherent and cannot be corrected. It further has been proved that as to speed of circulation, and resulting capacity, efficiency, minimizing of scale deposit on hot tubes, tube failures from steam locking, burning and pitting, and the lost time and expense of renewing the same, the Kidwell boiler stands ahead of others. That as to the necessary feature of water endurance, constancy of the same, steady water level regardless of fluctuation of load, elimination of moisture and superheating the steam, together with all-around dependability, ruggedness, and safety, it also outclasses all others. Further, that it is not a "competition" design made to peddle out at low initial cost, but precisely the reverse—a design including every feature necessary to produce the greatest output for the least operating cost, so that it will appeal to those who buy boilers as *instruments of service which yield the largest return upon an investment.*

600. It is these facts which among those who know of this boiler have won for it such instant and intense favor. It is these facts which, in accordance with the inflexible law of the survival of the fittest, will quickly place this boiler into the supreme lead in every land and industry where the safety of human life, convenience of operation, scientific economy in the generation of steam, and the careful investment of capital with reference to its earning power, are understood, appreciated and consistently control boiler selection and installation.

A Spark from the Furnace. No. 4

Since we have in sundry places in this book quoted from *The Friction of Progress, by* Dr. Crane, we consider it advisable to reproduce this excellent article here through the kind permission of *The Associated Newspapers,* New York, and Dr. Crane, who controls the copyright.

The Friction of Progress

By Dr. Frank Crane.

Short-sighted people, and that includes us all, fight against every force that tends to make them better, richer and happier.

No one man will admit this in his own case, but whoever is familiar with the facts of history recognizes the sad truth.

Almost every invention of labor-saving machinery has been bitterly denounced by the workers. And has eventually bettered their condition.

Arkwright's spinning jenny was the cause of riots among the cotton workers, who called it a device of the devil to turn the poor weavers into paupers. But this invention has given employment to hundreds, where the old system employed one, and at a better wage.

Some time ago it might have been said: "If all New York takes to taxicabs, thousands of stablemen and cab drivers will be driven from employment." They were. They were driven out of jobs as hostlers where they earned two dollars a day into jobs as chauffeurs and mechanics where they earn ten.

Steam engines put thousands of stage coaches out of business. But for every one coach driver it gives employment to hundreds of engineers, firemen, brakemen and conductors, who are more intelligent, better fed, and better dressed than their horse-driving ancestors, and have less arduous tasks.

The South violently resented the abolition of slavery, yet it would be hard now to find even a Southern politician who would advocate the owning of slaves again.

Some day and somehow the nations of earth will get together and by simple agreement eliminate war from future history. For war exists now, not as a necessity of human nature, but because statesmanship has not mastered the art of co-operation. But we may be sure that every step toward the "Parliament of Man" will be hotly contested, and that not by wicked men, but by earnest and well meaning men, in the name of patriotism and honor.

It is interesting, this waste incident to progress, this friction of the wheels of evolution.

When Saint Paul came preaching to a certain town, the idol makers of the place would have mobbed him, for "their craft was in danger."

Lichtenburg, in his "Reflection," says: "If mankind suddenly took to virtue, many thousands would inevitably be reduced to starvation."

Moral:—Even improvements in boilers are not always welcomed. See Section 277.

A Spark from the Furnace. No. 5

The Bishop and the Architect

A parsimonious bishop once commissioned an eminent architect to survey a church and prepare the necessary drawings and specifications for repairs and alterations.

After faithfully executing this commission the architect rendered to the bishop a bill for the moderate sum of one hundred pounds sterling.

But the reverend gentleman, not averse to trying the ancient scheme of getting something at less than its true value, summoned the architect and vociferously asserted that his charge was exorbitant, unreasonable and "entirely out of line." "Why, Mr. Architect," he exclaimed," many of my curates work for an annual salary less than your bill."

"Does your Grace accept a compensation of £100 per year?" asked the architect.

"Certainly not! You forget yourself, Sir, even to suggest such a thing! Remember, Sir, *I am a Bishop, not a curate!*"

"Just so, your Grace! Just so!" replied the architect. "And please remember that *I also am a Bishop in Architecture, and not a curate.*"

His bill was promptly paid.

Moral:—In architecture, boilers, or anything else, curate prices bring only curate results, and if you want Bishop grade of results *you must pay Bishop prices to get them!*

VII. Chimney Stacks for Water Tube Boilers

601. The Raw Materials needed to operate a boiler are air, water and fuel, and the resulting products are steam, ashes and gas. If the boiler is to operate successfully each of these products must be removed promptly, and in particular the gas must be taken away as fast as formed. To do this a stack, or the mechanical equivalent of it, is necessary, and its capacity must be such as to dispose of the quantity of gas produced *when the boiler is driven at the maximum rating to be developed.* Today boilers are driven at ratings far beyond those customary in the past, hence stacks of proportionately greater capacity are necessary. As the Kidwell boiler exceeds all others in capacity, it follows that if the maximum financial returns are to be obtained from it the stack to which it is connected must be of greater capacity than needed by ordinary boilers. As a clear understanding of this matter is vital the principles underlying the subject will now be explained.

602. Function of a Stack. It does two things:—(a) Removes from the furnace the gas as fast as formed, to make room for more gas and thus cause continuous combustion; (b) Brings the gas into intimate contact with the boiler heating surface so that the latter can extract the heat from this gas. Of the heat generated by the burning fuel, a portion is usually imparted to the boiler by direct radiation (see Sect. 175), but the larger portion is taken up by the gas, which acts as a vehicle to convey this heat to the boiler surface. Therefore, *this heat conveyor must travel continuously over every portion of the heating surface if the equipment is to function properly.* As fast as combustion proceeds the heat produced *must go somewhere,* and if not conveyed to the boiler surface where it can be utilized it will accumulate in the fire box as in a crucible, be soaked up by the furnace walls, and quickly overheat and destroy them. This frequently happens when, through a misunderstanding of the process, forced draft is applied in the ash pit with a view of dispensing with an adequate stack. See Sect. 684.

603. A Stack is a Pump. It is conventional to speak of a stack "pulling" the gas through the boiler. It really does nothing of the sort, but causes certain phenomena whose effect is to *push* the gas through the boiler and stack. Analogy:—Watch a pumping engine operate; in ordinary parlance we speak of the *suction* causing water to flow into the pump; actually the cause of flow is that the steam in the engine end *does work which pushes the water* in front of the pump plunger and forces it into the main. Therefore, it leaves behind this plunger a *vacuum,* and the weight of the water plus the atmospheric pressure above it unite *to push* this water into this vacuum. Therefore, the real driving force behind this operation is the steam in the engine, and the process requires *work* which the engine has to produce.

604. Similarly, pumping gas through a boiler requires work, and as all work about the boiler has its origin in the heat produced in the furnace, *this operation requires heat,* and the amount so needed is not available for generating steam, hence is analogous to friction in an engine, or the loss in the exciting coils of a dynamo. Therefore, the gases in a stack must always cause a heat loss, so the fuel efficiency of a boiler can never be 100%. The hotter the gases are when they enter the stack the greater the amount of heat they carry out, hence the less the fuel efficiency of the boiler will be.

605. In any given case the work done in pushing the gases through a boiler can be computed, but as the method is too long to be given here, the reader is referred to p. 365 of Bulletin 23, Bureau of Mines, *Steaming Tests of Coals,* or to p. 324 of Gebhardt's *Steam Power Plant Engineering,* from which it will appear that considered as *a gas pump only* the efficiency of a stack is extremely low, much less than that of an induced draft apparatus, but its other advantages offset this deficiency for stacks whose height does not exceed those named in Sect. 667.

606. Draft the Pushing Force in a Stack. In a U-tube like Fig. 15 pour into one leg some water and into the other some mercury. The mercury side will stand at a level lower than that of the water, because a short column of it will balance a high column of water. If both columns are of same height to start with, the mer-

cury will sink and the water will rise, so *a flow results,* and it will continue until equilibrium is obtained, then the flow will stop.

607. Similarly, a chimney in operation contains a column of gas which is *hotter, therefore lighter per cubic foot,* than the outside air, hence the cold air presses harder on the exterior of the stack at the bottom than does the inside hot gas. If a hole be cut into the bottom cold air will rush in; now suppose that at this entrance we place an electric arc or other means by which just as this air enters it also becomes heated to the stack temperature, then the difference between the inside and outside pressures will be maintained, the entering hot air will force out of the stack an equivalent volume of the original hot gas, and the operation will be continuous.

This is precisely what occurs in a stack, except that when properly designed the equipment is so arranged that the only path by which outside air can enter is through the fuel bed, and while so passing it maintains combustion and therefore enables the boiler to operate.

608. Natural and Induced Draft. If the draft is produced by a chimney in the manner above explained it is called natural draft. It can also be produced by a fan which is placed beyond the damper and produces in the breeching a suction equivalent to that of a stack, and is then called induced draft. In the latter case the stack height need be only that necessary to deliver the gases to an altitude sufficient to prevent nuisance or comply with local ordinances. To drive the fan, work has to be done upon it, and for cases where the load does not vary greatly and stacks of reasonable height will answer, it will be found cheaper in operation to use natural draft. But where heavy overloads occur at intervals, or the fuel requires great draft, so that stacks of suitable capacity would have to be of excessive height, then induced draft, either alone or in combination with a reasonably high stack, will be the cheaper method to use. See Sect. 667.

Some good information on production of draft is given in *Forced and Induced Draft with Mechanical Stokers,* on p. 28 of *Combustion* for January, 1922.

A unique induced draft equipment is the Evasé stack as described in Sect. 700.

609. Forced Draft. This term is usually confined to draft mechanically produced and applied in the ash pit to drive air through the fuel, as done with many stokers. See Sects. 678 to 681. But the rather current idea that such draft can act as a substitute for a stack of proper height is in error, for which see Sect. 684.

610. Draft Gauge. Since draft is a pressure difference it can be measured in lbs. per sq. ft., or in other units, but as such pressure is small the most convenient way of measuring is by the difference in height of water in the branches of a U-tube, one of which is connected to the inside of the stack while the other is open to the outside air. The latter pushes the water downward until equilibrium of pressure is obtained in the two columns, and the difference between the levels of the two water surfaces, expressed in inches or a fraction thereof, gives the intensity of the draft. This intensity depends upon the temperature of the gas and that of the outside air, the height of the stack, and the barometer reading, and other factors named in Sects. 701 and 704. As the barometer fluctuates constantly through a small range this factor may be neglected in all cases except at high altitudes, for which see Sects. 698 and 699. For further simplicity it is usual to compute the drafts corresponding to various gas and air temperatures for a stack 100 feet high, and then pro rate for other heights.

611. Draft Table. Table 8 from Gebhardt's *Steam Power Plant Engineering,* p. 281, gives drafts so computed and over a sufficient range to cover any case where good results are obtained. These are the *static* drafts, or those which would be indicated on the gauge in case the hot gas in the chimney is at rest.

612. How the Draft is Used Up. If water circulates around a U-tube like Fig. 7 all of the head (draft) producing the flow is used in overcoming the friction of the tube walls, and in causing velocity in the effluent. In precisely the same way stack draft is used up in doing the following things:—(a) Pushing air into the ash pit and through the bed of fuel; (b) Adding velocity to the furnace gas and causing it to flow through the boiler and sweep the heating surface so that it finally arrives at the damper; (c) Compelling the gas to travel from damper through any ducts, flues, etc., between damper and stack; (d) Forcing the gas to travel from the entrance point in the stack to the top. Each of these stages, or such of them as exist in any given case, use up their quota of the draft, but the sum of them *always equals the total* as computed from Table 8.

613. Available, as Distinguished from Total, Draft. In any practical case the procedure followed when designing a stack is thus:—The maximum rating at which the boiler is to be operated, the kind of fuel, the method of firing it, and the maximum quantity to be burned, are all settled, from which the quantity of gas to be produced is computed, and the next step is to determine how to make it flow through the boiler. The resistances to flow from ash pit door to the damper, or the stack entrance, all expressed in terms of draft, are summed up, and the next step is to determine how to produce and apply that draft *at the proper point, namely, the point where the gas enters the stack.* Unless the amount of draft so computed is applied at that point the boiler cannot operate at the predetermined rating.

614. The draft thus computed is called *the available* draft, since it is the net amount which must be provided at the given point in order to do the work. But when the gas flows from that point to the top of the stack, additional draft is needed, and this is the amount used up in the stack itself. Therefore, the available draft is that used up from the start to the point where the gas enters the stack, and the remainder is the part used by the stack, and the sum of these is the *total or theoretical or static* draft as computed from Table 8.

TABLE 8.

THEORETICAL DRAFT PRESSURE IN INCHES OF WATER. CHIMNEY 100 FEET HIGH.[1]

Temp. in the Chimney.	Temperature of the External Air — Barometer, 14.7 Pounds per Square Inch.[2]										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
220	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
240	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
260	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
280	.584	.549	.515	.432	.451	.422	.394	.365	.340	.313	.288
300	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
320	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
340	.662	.638	.593	.563	.530	.501	.472	.443	.419	.392	.367
360	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
380	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
400	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
420	.753	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
440	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
460	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
480	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
500	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534
550	.863	.828	.795	.762	.731	.700	.671	.644	.618	.593	.585
600	.908	.873	.839	.807	.776	.746	.717	.690	.663	.638	.613

1. For any other height multiply the tabular figure by $\frac{H}{100}$, where H is the height in feet.

2. For any other pressure multiply the tabular figure by $\frac{P}{14.7}$, where P is the barometric pressure in pounds per square inch.

615. Percentage of Draft Lost in Stack. By suitable proportioning of the stack dimensions it is possible to make the draft loss in a stack any desired percentage of the total draft. Practically, however, there are limits. Cost enters the problem, and the larger the stack the

more surface available for cooling the gas (see Sect. 670), and this in turn reduces the draft. Again, if the number of boilers connected to the stack varies greatly during the day, the quantity of hot gas available when the load is slack may be insufficient to fill the stack, in which case the gas flows up like the bubbles in Fig. 78B and cold air flows down the sides, hence the draft is seriously reduced, or practically extinguished.

616. It has therefore been found that for average conditions a draft loss of 20% in the stack is the most economical, and that proportion will be assumed hereafter unless otherwise stated. Therefore, *the available draft will be 80% of the total draft produced by the stack.*

It is possible to change this proportion, however, and as shown in Sects. 659 to 661 the stack loss can be made any percentage desired.

617. Relation Between Draft and Quantity of Gas Flowing. The resistance to gas flow which the draft has to overcome increases as the square of the gas velocity, therefore also as the square of the quantity flowing if the area of the passage remains unchanged. The *work* required to move the gas increases as the *cube* of the velocity, or quantity. Thus, if the quantity be doubled, the velocity is doubled also. To move the original quantity at the double velocity will require 4 times as much work as before, hence to move twice that quantity will double the work again, hence the final work will be $2\times2\times2=8$ times that necessary to move the original quantity, so the work varies as the cube of the velocity or gas quantity. This illustrates clearly why ample stack capacity is necessary for high ratings.

618. It follows that before we can work out the stack needed in any case we must determine *how much gas it must handle,* and the temperature of that gas. We must also ascertain what the resistance of the gas passages will be, *and what rate of gas flow* corresponds to such resistance, otherwise any statement of resistance or draft loss is useless. The requirements can be met if we can determine:—(a) The draft loss in breechings or flues; (b) The draft loss through the boiler itself; (c) The draft loss through the fuel bed. These will sum up equal to the available draft which must be provided, from which the total draft to be produced by the stack can be computed.

619. Quantity of Gas per Boiler HP. This depends on the kind of fuel, and especially on the method of firing. It requires an unusually good fireman to burn coal in a hand fired furnace with 24 lbs. of air per pound of coal, and usually the quantity is greater. But with modern stokers this quantity can be reduced to 18 lbs. or less. When solving any stack problem it is therefore necessary to determine whether hand or stoker firing is to be used.

620. Quantity of Gas per Pound of Coal. If 24 lbs. of air are used per pound of coal, 25 lbs. of gas result. But in practise the weight of gas is taken as identical with the weight of air used, and even then the allowance is ample, because no account is taken of the percentage of ash in the coal, and this more than offsets the difference.

621. Capacity of Stacks for Hand Fired Boilers. Before stokers came into use it was generally assumed that 150% of boiler rating was the maximum that could be got by hand firing, and it was further assumed that if a stack were proportioned on the basis of burning 5 lbs. of coal per rated boiler horse power per hour, with 24 lbs. of air per pound of coal, that could meet any condition that might arise as to overload, or need of burning poor fuel in emergencies. Accordingly, stack formulas and tables were worked out on that basis, and many of these are still in current use. This is equivalent to allowing $3\frac{1}{3}$ lbs. of coal, or 80 lbs. of gas per boiler HP. at rating, equal to 5 lbs. of coal or 120 lbs. of gas per *rated* HP. when operating at 150% of rating. This gas allowance is excessive if a stoker is used, hence in such case the only safe method of using any tables or stack curves is *to ignore the tabulated HP. values, and base all computations on the maximum quantity of gas to be handled.* How this is done will later be shown.

622. Dimensions of, and Draft Losses in, Breechings. These depend upon the cross section, shape, and length of the breeching, material of which it is made, the number of turns in it, and quantity of gas to be conveyed.

If a stack rests directly upon the boiler or setting, the stack shaft is flared at the bottom sufficiently to cover the damper plate, so that the net stack height is figured from this plate, and the draft loss in breeching need not be taken into account.

623. When boilers are connected to a transverse breeching which conveys the gas to a stack, *the net stack height* must be computed from the center of the breeching opening into the stack, as shown in Sect. 650. The deter-

mination of the proper dimensions of such a breeching is not always easy, but this item is of such importance that it should never be slighted or guessed at. There are numerous rule-of-the-thumb methods of determining the cross section through the breeching, such as allowing a given area per boiler HP., or making the section bear some ratio to the grate surface, etc. It is evident that the shape of the breeching, the smoothness or roughness of the material forming its walls, and above all, *the quantity of gas flowing*, all vitally affect the problem, hence the above stated methods represent guesswork and should never be used except for rough preliminary approximations. The following reliable method is therefore presented, and it is easy to apply.

624. It is evident that if the proper stack diameter is ascertained, and the breeching is made circular and of identical diameter with the stack, the gas velocity in both will be identical, and the combination will operate with satisfaction. But, as the breeching is horizontal, or approximately so, *it cannot produce any draft*, hence the draft necessary to pull the gas through it must be supplied by the stack, precisely as the latter must supply draft to pull the gas through the boiler. See Sect. 642. Therefore, so far as *draft alone* is concerned, the breeching may be considered merely as an extension of the gas passages through the boiler.

625. But here two other factors enter. The resistance to the gas flow through a horizontal duct is considered to be somewhat greater than through one placed vertical. Again, soot or dust will settle to the bottom of the breeching and thus reduce its effective area, and increase its frictional resistance. Means should always be provided for removing such deposits, yet, even in that case, as a safeguard it is considered advisable to increase the size of passage over what would be necessary if the gas were free of dust. It has been found that if the cross section of a circular breeching be made about 20% greater than that of a stack as computed by the methods given in the later Sections, such increase in sectional area is ample to compensate for the two factors above mentioned.

Therefore, if the breeching is made of steel, and is circular in cross section, determine the maximum quantity of gas it must handle as in Sects. 618 to 621, and 645 to 647, including leakage allowance per Sects. 639 and 640. To this add 20% as above stated, then divide the amount so found by 120, to reduce it to the equivalent stack HP. as plotted in Fig. 204, then from the steel stack curve in this figure take off the diameter of stack to correspond, as per Sect. 647, and this will be the required breeching diameter necessary to handle that quantity of gas with reasonable draft loss.

When many boilers are connected to one long breeching the latter is preferably tapered, and to get the smallest section at the far end from the stack, proceed exactly as above, except that the maximum quantity of gas delivered by the end boiler is to be assumed as a basis upon which to compute the end section.

626. If the breeching is not circular, but square, rectangular, oval, etc., its cross section should be *not less* than that above determined for a circular breeching, but the draft loss will be greater than through the circular form, as shown below, because the amount of surface swept by the gas is greater. Allowance for this is made below, but in addition thereto an increase of 5% to 10% of the cross section is recommended if space permits.

627. Assuming that the boilers are operating *at rating* and delivering into the breeching 80 lbs. of gas per *rated* HP. per hour, the draft loss through a circular steel breeching 100 feet long and of the diameter determined by the above method, will be 0.1-inch of water, and *pro rata* for other lengths. For a square breeching of identical cross section, the resistance should be taken 15% greater than the above, and for a rectangular section with sides 1 to 2, allow 20% of increase, because of the additional wall surface swept by the gas.

If a brick flue is used, determine the area of a brick stack from Fig. 204, and find the equivalent square or rectangle, and allow extra draft loss as above stated.

628. When several boilers are connected to the same breeching, determine the loss from the stack up to the first boiler connected to the breeching, and allow a further loss of 0.05-inch for each additional boiler. See Gebhardt, *Steam Power Plant Engineering*, p. 322. If the breeching is not straight, allow 0.05-inch loss for each right-angled turn, and to keep the loss down to this figure the radius of such turn should not be less than 50% greater than the diameter or width of the breeching.

When summing up the drafts as per example in Sect. 652, the draft loss computed as above must in any practical case be increased as the *square of the rating* the boiler is developing

while producing the maximum quantity of gas assumed when computing the stack. The easiest way to do this is to sum up the draft loss through boiler and breeching together, when operating at *rated* HP., then correct for the actual maximum capacity to be developed, as shown in Sect. 633.

629. Long or complicated breechings greatly reduce the draft, and require from 20 to 50 feet of extra stack height to overcome the loss thus caused, hence they should be avoided if possible. Underground flues are even more objectionable, as they not only add extra length to the gas courses in the boiler without sweeping any additional heating surface, but they are inaccessible, difficult to clean, more liable than overhead flues to cool the gases, and frequently accumulate water from ground leakage, or even become flooded during storms.

630. If an economizer is used its draft loss must be figured in as part of the loss in the breeching.

631. Draft Loss Required to Accelerate the Gas. Prof. Gebhardt, in *Steam Power Plant Engineering*, p. 287, says:—"The draft required to accelerate at sea level from zero velocity to velocities of 10, 20, 30, and 40 feet per second at a temperature of 550 deg. Fah. is 0.012, 0.048, 0.108 and 0.192-inch respectively. Except at high velocities the draft is small and may be neglected in the problem of chimney design." As we shall later provide for a leakage allowance, that may be assumed to cover this item.

632. Draft Loss Through the Boiler. This varies greatly with the boiler design, arrangement of the gas baffles, number of gas passes, amount of air used per pound of fuel, and rate at which the boiler is operating. Consult Gebhardt, pp. 285 to 287, and note his Table 53 which records the draft loss through a large number of boilers of different types.

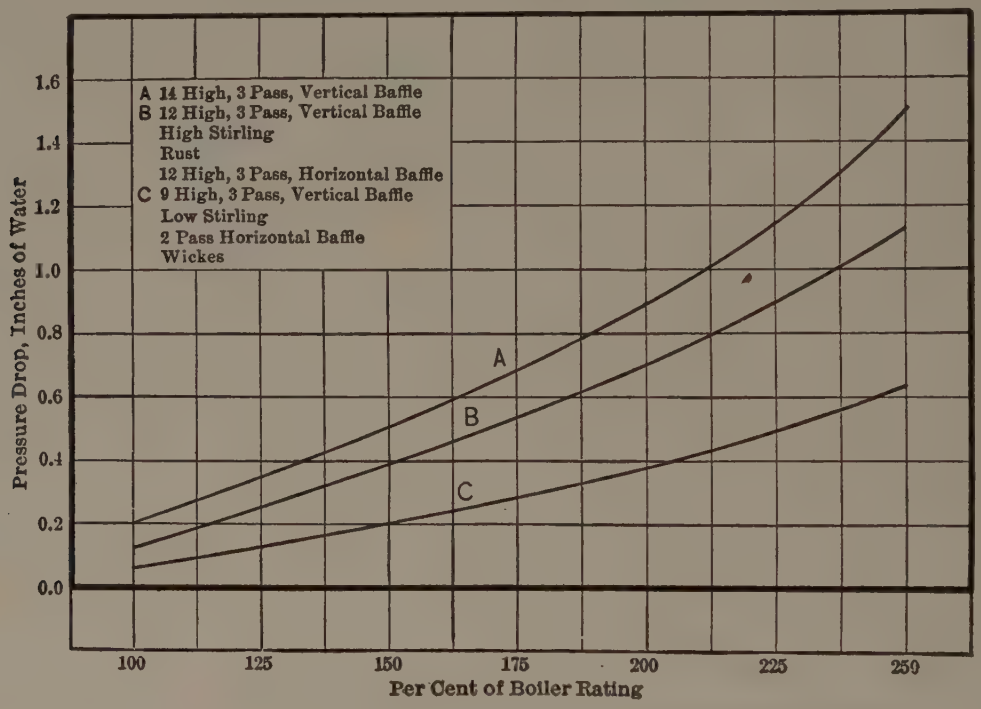


FIG. 200. DRAFT LOSS THROUGH BOILERS BETWEEN FURNACE AND DAMPER

633. If Kidwell boilers are operated at rating (which they should not be, as shown in Sects. 482 to 499), the draft loss on basis of 80 lbs. of gas per HP. will vary from 0.15 to 0.2-inch of water and not less than the latter figure should always be assumed. For very high boilers 0.22 to 0.25-inch should be allowed under the same conditions. If a superheater is installed, that will add from 0.03 to 0.06-inch of loss, *or more*, which must not be overlooked. The draft loss is to be figured as increasing with the square of the rating, as shown in Sect. 617. This is well illustrated by Fig. 200 from Gebhardt, p. 286, which shows that in boilers with staggered tubes and vertical cross baffles the resistance increases

faster with the rating than in others. In these curves the loss increases somewhat faster than the square of the rating, but this is more than compensated for by the liberal allowance at rating, which exceeds that shown in the curves.

634. When by using a stoker or by other means the quantity of gas per pound of fuel is decreased, the draft loss at any rating can be

C=draft loss at rating, given in Sect. 383.
R=boiler rating at which the loss is wanted, expressed in terms of the nominal or standard boiler rating.
Q=lbs. air per lb. of fuel.
L=draft loss at rating R, in inches of water.

Example:—Assume that the draft loss at rating with 24 lbs. of air per lb. of coal is 0.2-inch,

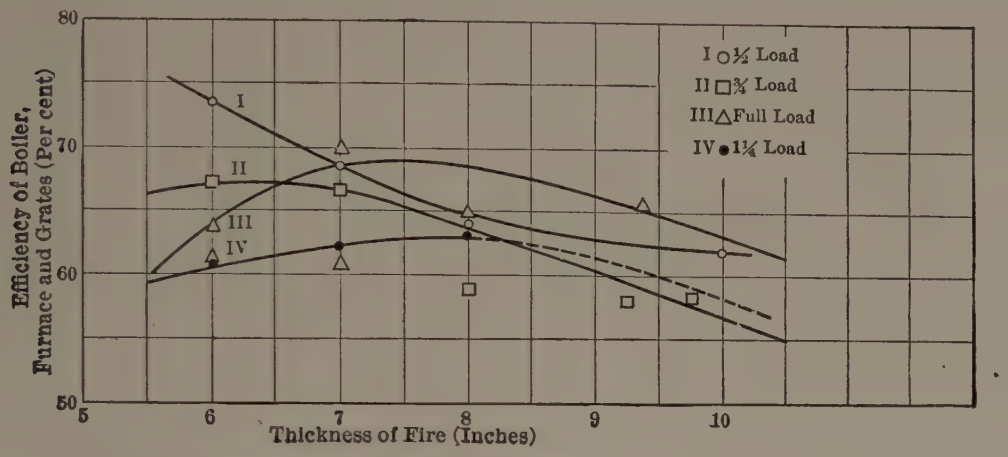


FIG. 201. SHOWING VARIATION OF EFFICIENCY WITH THICKNESS OF FUEL BED

TABLE 9.

COMBUSTION RATES, LBS. OF COAL PER SQ. FT. OF GRATE PER HOUR, AND CORRESPONDING DRAFT LOSS THROUGH FUEL BED.

Variety of Coal	Draft Loss Through Fuel Bed Only (Inches of Water)								
	0.1	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Bituminous, run of mine	20.0	28.0	33.5	38.5	43.0	47.0	50.5	....	....
" slack	14.0	19.5	24.0	28.5	32.5	36.0	39.0	41.5	44.0
Bituminous crushed mine run and 1½-inch screenings on chain grate	10.0	15.0	19.0	22.5	25.5	28.5	31.0	33.5	41.0
Rocky Mountain Lignite	16.0	21.5	26.5	31.0	35.0	38.5	40.5	44.0	47.5
Semi-bituminous, run of mine	12.5	16.5	20.0	23.5	26.5	29.0	31.5	34.0	36.0

determined by using the above figures as a base, and multiplying them by the square of the rating and the square of the quantity of gas per pound of fuel divided by 24, or in a formula,

$$L = R^2 \times \left(\frac{Q}{24}\right)^2 \times C$$

In which

and that we want the loss at 200% of rating when using a stoker requiring a maximum of 18 lbs. of air per lb. of coal. Then C=0.2, R=2, Q=18, from which L will work out as 0.45-inch.

635. Draft Loss Through Fuel Bed. In all cases except where a forced draft apparatus applies in the ash pit the pressure necessary to

drive the air through the fuel bed, the stack or induced draft must produce the necessary pressure difference. This varies greatly with the fuel efficiency to a considerable degree, as shown in block H, Fig. 47, and in Fig. 201 which applies to Illinois coals, and is from *A Study of*

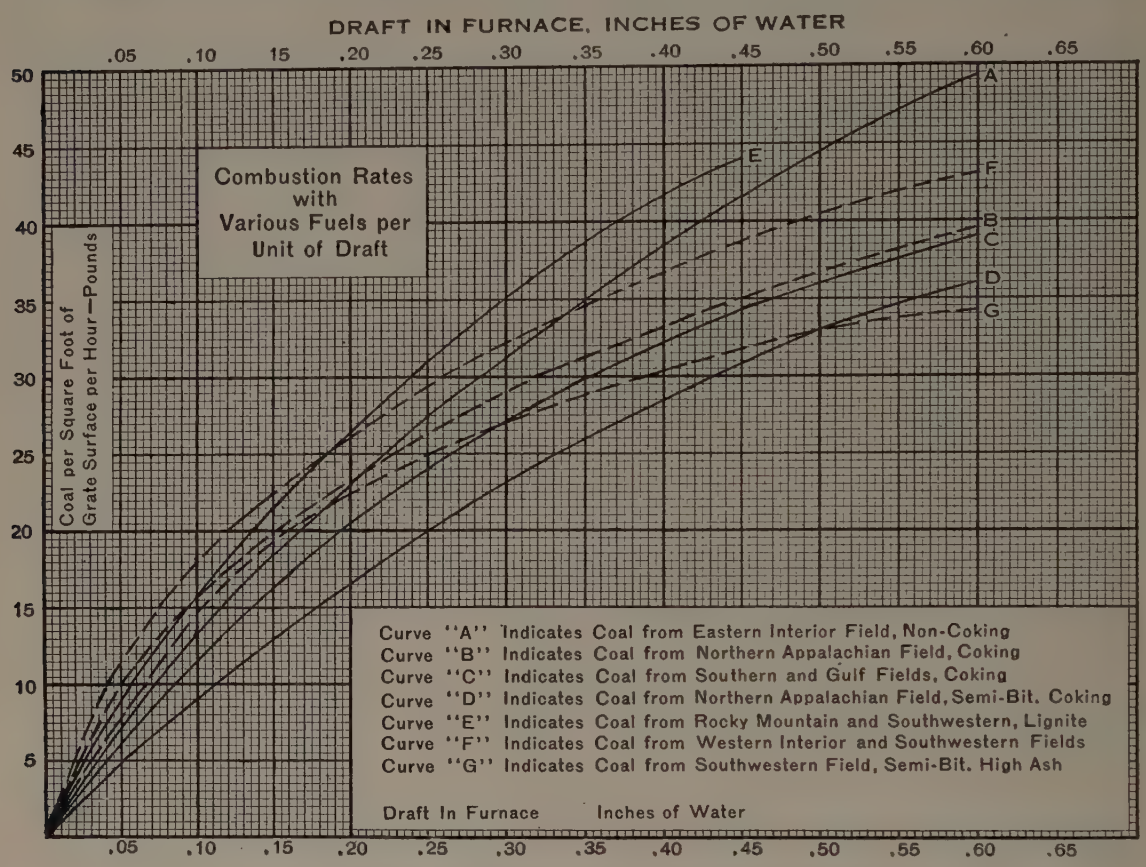

DRAFT IN FURNACE, INCHES OF WATER
.05 .10 15 .20 .25 .30 .35 .40 .45 .50 .55 .60 .65
50 45 40 35 30 25 20 15 10 5
Combustion Rates with Various Fuels per Unit of Draft
Coal per Square Foot of Grate Surface per Hour—Pounds
A
E
F
B
C
D
G
Curve "A" Indicates Coal from Eastern Interior Field, Non-Coking
Curve "B" Indicates Coal from Northern Appalachian Field, Coking
Curve "C" Indicates Coal from Southern and Gulf Fields, Coking
Curve "D" Indicates Coal from Northern Appalachian Field, Semi-Bit. Coking
Curve "E" Indicates Coal from Rocky Mountain and Southwestern, Lignite
Curve "F" Indicates Coal from Western Interior and Southwestern Fields
Curve "G" Indicates Coal from Southwestern Field, Semi-Bit. High Ash
Draft In Furnace Inches of Water
.05 .10 .15 .20 .25 .30 .35 .40 .45 .50 .55 .60 .65

FIG. 202. FROM DATA COMPILED BY GREEN ENGINEERING CO.

TABLE 10.

DRAFT PRESSURE REQUIRED TO BURN CERTAIN FUELS.

Kind of fuel	Total draft in inches of water	Kind of fuel	Total draft in inches of water
Straw	0.20	Slack, very small	0.7–1.1
Wood	0.30	Coal dust	0.8–1.1
Sawdust	0.35	Semi-anthracite coal	0.9–1.2
Peat, light	0.4	Mixture of breeze and slack	1.0–1.3
Peat, heavy	0.5	Anthracite, round	1.2–1.4
Sawdust mixed with small coal	0.6	Mixture of breeze and coal dust	1.2–1.5
Steam coal, round	0.4–0.7	Anthracite slack	1.3–1.8

kind of coal, its size and the amount of dust and dirt in it, the extent to which it clinkers and clogs the air spaces in the grates, and the thickness of the fuel bed. The latter also affects the *Boiler Losses* by A. P. Kratz, Bull. 78, Engineering Experiment Station, University of Illinois. This, of course, changes the quantity of gas flowing through the stack, hence affects the

draft. Every one operating hand fired boilers should consult *Fuel Economy in the Operation of Hand Fired Power Plants,* Circular No. 7, Engineering Experiment Station, University of Illinois, and Technical Paper 80, Bureau of Mines, *Hand Firing Soft Coal Under Hand Fired Boilers.*

derived from their long experience in burning such fuels on their chain grate stoker as shown in Fig. 191.

Table 10 from p. 176 of *Engineering of Power Plants* by Fernald and Orrok is useful as a suggestion, but its value is less than it might be because the number of lbs. of fuel burned per

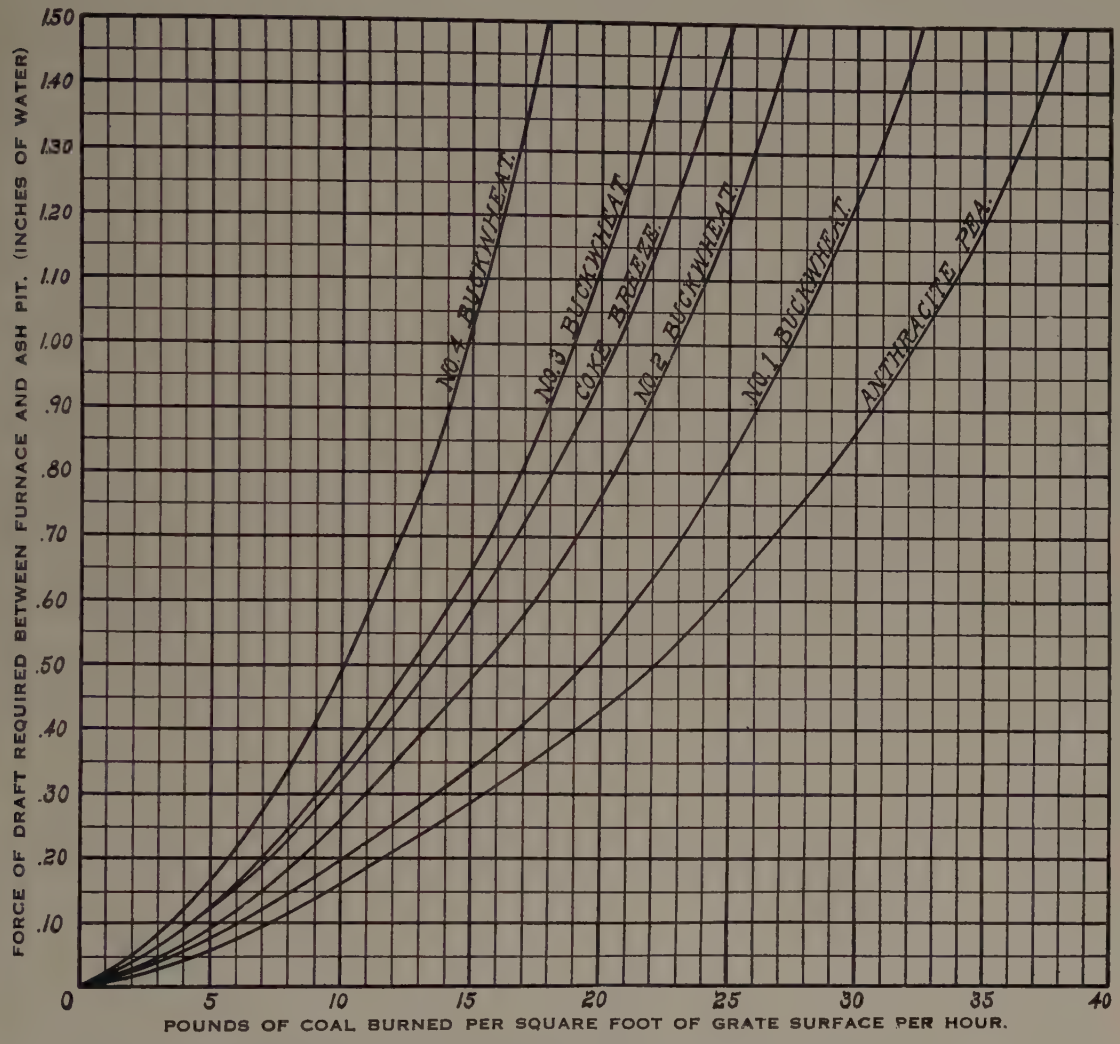


FIG. 203. CURVES SHOWING DRAFT BETWEEN FURNACE AND ASH PIT AT DIFFERENT COMBUSTION RATES FOR SMALL ANTHRACITE AND COKE BREEZE

636. All that can be done here is to give average values of the draft required to burn varying amounts of coal of different kinds per square foot of grate per hour, and Table 9 contains information derived from many sources. Fig. 202 gives similar information based on classifications of coals as to their coking or non-coking quality, and was contributed by Green Engineering Co., East Chicago, Indiana, and is

sq. ft. of grate is not given. The tabular values probably indicate the authors' judgment as to the amount of draft the stack should be able to produce when the boilers are hand fired with the fuels named.

637. Draft Required for Burning Small Sizes of Anthracite. Accurate data on this subject are scarce, and we are under great obligation to Mr. Wm. P. Frey, Fuel Engineer of The Lehigh

Coal and Navigation Co., Lansford, Pa., who generously placed at our disposal the results of his extensive experience, from which the following information has been prepared. Fig. 203 shows the draft required to burn all sizes of anthracite now used for steam generation, and is based on forced draft chain grate practise, normal air spaces about 5% and operating at 180% to 200% of boiler rating based on 10 square feet of heating surface per rated HP. The sizes of fuel named on the curves are given in Table 11.

All sizes are allowed 20% undersize and 10% oversize.

The curves in Fig. 203 are based on the assumption that the thickness of fuel bed on the stoker is 6 inches for pea and No. 1 buckwheat, and 5 inches for the smaller sizes. If a different thickness be used the draft must be increased or decreased to correspond.

TABLE 11.

GRADING OF SMALL ANTHRACITE.

Kind	Will Pass Over	Will Drop Through
Pea	½″ Round Mesh	¾″ Round Mesh
No. 1 Buckwheat	5/16″ " "	½″ " "
No. 2 Buckwheat	3/16″ " "	5/16″ " "
No. 3 Buckwheat	3/32″ " "	3/16″ " "
No. 4 Buckwheat	3/64″ " "	3/32″ " "

In case the boilers are hand fired the combustion rate with any given draft will be from 2 to 4 pounds less per square foot of grate than shown by the curves. Valuable information as to burning such material in hand fired furnaces, either alone or mixed with soft coal, is given in Technical Paper 220, Bureau of Mines, *Burning Steam Sizes of Anthracite.*

Mr. John E. Muhlfeld contributed to American Society of Mechanical Engineers, June, 1918, a valuable paper on *Utilization of Fine Sizes of Anthracite,* which may also be found in *Power,* July 23, 1918, p. 143. This discusses methods of burning such fuel, both straight, and when mixed with soft coal, and presents results of some tests. It should be read by everyone who has to burn such fuels.

638. Draft for Burning Coke Breeze. This material, formerly discarded as worthless, is now burned with great success by use of proper stokers. Kidwell boilers equipped with forced draft chain grate stokers arranged for burning coke breeze have operated for 5½ months *continuously* at from 200% to 300% of rating without any difficulty whatsoever, and with entire satisfaction. Fig. 203 shows the draft required for such material when burned on forced draft chain grate stokers, and consisting of a mixture of sizes varying from that of No. 1 to No. 3 buckwheat.

639. Draft Loss Due to Leakage. This is far larger than usually realized. In poorly built plants 25%, or even double that amount, is lost through leaks. Where stacks rest on damper plates and have no seal around the joint the leakage is usually excessive. It is for this reason that such extreme care is taken in arranging the stack and breeching connections of the Kidwell boiler, as shown in Figs. 173 and 174.

Cracked settings, carelessness in packing around blow off pipes, frames, etc., and the poorly fitted doors which are furnished with "cheap" boilers, all cause leaks which affect the draft. If the stacks and breechings are too small the draft necessary to accelerate the gas is also an item to be figured.

To be efficient a stack *must be tight.* This is not as well realized as it should be, and masonry stacks in particular are often deficient in this respect. Every joint must be properly filled with mortar. Precisely the same precautions are to be used here as when building the boiler setting, all of which are fully set forth in our specifications for Boiler Settings for which see Sect. 423.

640. The allowance to be made for leakage loss when computing the stack dimensions must be judged for each case according to the conditions. There are two ways in which to do this. (*a*) Increase the computed quantity of gas to be handled, by 10% to 25% or more, according to the conditions, and this will make a corresponding increase in the stack cross section. This is the preferable method, and usually the cheaper also. (*b*) Increase the stack draft so as to pull through more gas. This is usually the more costly method, hence is not to be preferred. But, as it will better illustrate how to compute drafts, we will use it in the following computations, and assume that a 10% increase in the stack draft will be a sufficient allowance.

641. Draft Loss Through Dampers. This varies through such wide limits that no average is possible. It is common to find that the damper frames and openings furnished with "cheap"

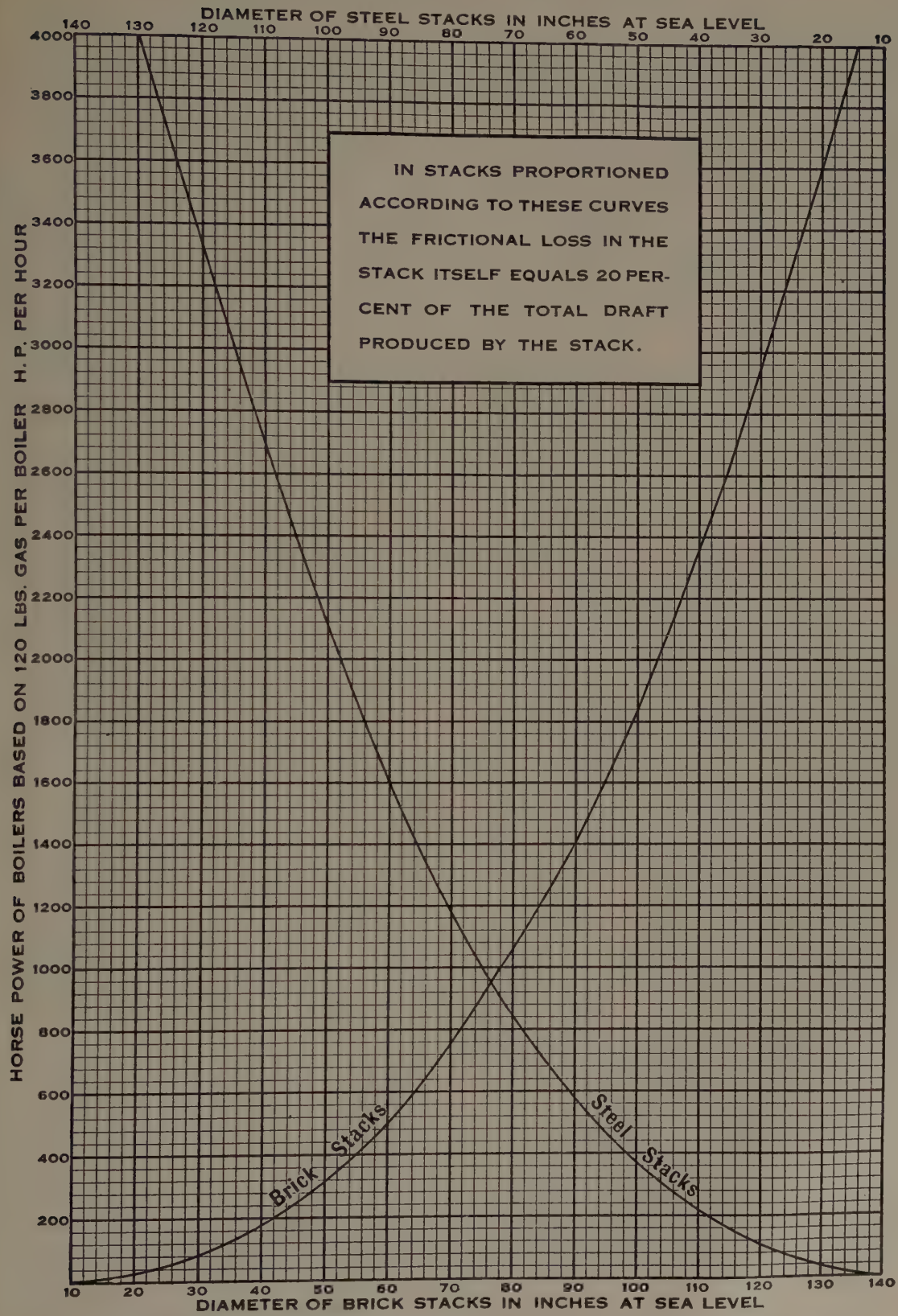

DIAMETER OF STEEL STACKS IN INCHES AT SEA LEVEL
140 130 120 110 100 90 80 70 60 50 40 30 20 10
HORSE POWER OF BOILERS BASED ON 120 LBS. GAS PER BOILER H. P. PER HOUR
4000 3800 3600 3400 3200 3000 2800 2600 2400 2200 2000 1800 1600 1400 1200 1000 800 600 400 200
IN STACKS PROPORTIONED ACCORDING TO THESE CURVES THE FRICTIONAL LOSS IN THE STACK ITSELF EQUALS 20 PER-CENT OF THE TOTAL DRAFT PRODUCED BY THE STACK.
Brick Stacks
Steel Stacks
10 20 30 40 50 60 70 80 90 100 110 120 130 140
DIAMETER OF BRICK STACKS IN INCHES AT SEA LEVEL

FIG. 204. CURVES SHOWING DIAMETER OF STACKS AT SEA LEVEL FOR OPERATING HAND FIRED BOILERS 50 PER CENT ABOVE RATING. FIGURES ON LEFT HAND SIDE INDICATE RATED HP. OF BOILERS

boilers are so restricted in area that high ratings cannot be obtained with a stack of any reasonable height. Our practise as to that detail is explained in Sect. 440, and with damper areas as therein described no account need be taken of the damper friction when computing the stack dimensions.

For satisfactory work the damper area should not be less than 20% of the grate area for hand fired boilers, and 25% for stoker fired boilers. For stokers developing high ratings even a larger allowance is desirable, if not indeed necessary.

642. The Required Stack Dimensions are the *internal or net diameter, and the net height.* The method of procedure is to determine what diameter is necessary to handle the maximum quantity of gas produced, and then to compute the height necessary to create the draft required to force this quantity of gas through the fuel, boiler, breeching and stack, or such of these as are not eliminated by use of draft apparatus. The distinction between *net and gross* stack height as defined in Sect. 650 must be clearly noted.

Stacks for Hand Fired Boilers.

643. Stack Diameters. There are numerous formulas for determining stack dimensions, concerning which see Sect. 671. To use the method above described we shall employ one which gives the diameter necessary, and which has been proved reliable by many years of use.

644. Influence of Stack Material on Capacity. It is first necessary to point out that two stacks of identical dimensions will vary in capacity if made of different materials. The smoother surfaces of iron or steel stacks cause less frictional loss than the rougher surfaces of brick or concrete stacks. In consequence, a masonry stack must on the average have a diameter 6% greater than a steel stack of the same capacity, and this ratio is assumed in what follows.

645. Bell's Stack Formula. Mr. John E. Bell derived a formula connecting the capacity and diameter of a stack, as follows:—

For steel stacks, $HP.=\left(\frac{D}{4.68}\right)^{\frac{5}{2}}$

For masonry stacks, $HP.=\left(\frac{D}{4.92}\right)^{\frac{5}{2}}$ In which

D= net internal stack diameter in inches.

HP.=*rated* HP. of the boiler.

The diameters so found are sufficient to pass 120 lbs. of gas per *rated* HP. per hour, which means they can operate the boilers up to 150% of the given rating, and take care of a combustion rate of 5 lbs. of coal per hour per *rated* boiler HP., which is the basis on which stacks for hand fired boilers are figured. See Sect. 621.

646. From these formulas Fig. 204 is plotted. This gives a gas velocity in a steel stack 80 inches in diameter of about 1650 feet per minute if the gas temperature averages 500° Fah. For smaller stacks the velocity will be somewhat less, and for larger diameters it will be somewhat greater, but in either case, the dimensions are such that 20% of the total draft produced by the stack is lost in the stack itself, due to friction of the gas against its walls, hence the remaining 80% of the draft is available for use at the point where the breeching enters the stack, as explained in Sect. 616.

647. Fig. 204 is easy to use for any other conditions as to air supply per pound of fuel. Thus, suppose it were desired to ascertain the diameter necessary for a battery of boilers when fired by a stoker burning a maximum of 4000 lbs. of coal per hour with an air supply of 20 lbs. of air per pound of coal. Proceed thus:—20×4000=80,000 lbs. of gas per hour. The curves are based on 120 lbs. of gas per HP. per hour, hence 80,000÷120=750, which is the HP. of stack to select, and from the figure a diameter of 66 inches for a steel stack, or 68 inches for a brick stack, are the nearest commercial sizes which meet the requirements.

648. Height of Stack. The height necessary to produce at the stack base any given draft depends upon: (a) The temperature of the gas inside the stack; (b) The temperature of the air outside the stack; (c) The barometer pressure at the time, since this affects the density, hence the weight per cubic foot, of the external air. In all practical cases this latter requirement may be neglected for any locality 1500 feet or less above the sea level, and for greater elevations a correction factor must be used as shown in Sect. 698.

649. When designing stacks it is usual to assume the average external air temperature as 50 to 70 deg., according to locality, and the gas temperature as 500 to 550 deg. in cases where the stack must operate the boilers at heavy overloads, during which time the gases may go out at higher temperatures than normal.

650. The Height of Stack as derived by the following methods is the *net height,* or *that as measured above the boiler damper, or the point*

where the breeching enters the stack, or such other point as is assumed as the datum for which the available draft (see Sect. 614) is computed. Such point may be 20 to 30 feet above the firing floor level, hence the *total stack height* will be the net height plus the additional distance to the datum line assumed as the stack base.

651. Practical Example. Let us assume a boiler rated as 500 HP., hand fired, with 100 square feet of grate surface, connected to a stack placed behind the boiler with a straight breeching whose draft loss at rating will be 0.02-inch, and that the boiler is to operate at 150% of rating when burning run of mine semi-bituminous coal. Assume a stack temperature of 500 deg. and an average outside air temperature of 70 deg. What size of stack will be required?

652. Coal of this grade will require about 3¼ lbs. per boiler HP., hence the quantity to be burned per hour will be $500 \times 1.5 \times 3.25 = 2437.5$, say 2450 lbs., or 24½ lbs. per square foot of grate. From Table 9 the draft loss through the fuel bed will be 0.27-inch. The draft loss through boiler and breeching will be $(0.2+0.02) \times (1.5)^2 = 0.22 \times 2.25 = 0.495$-inch. The total loss up to where the breeching enters the stack is therefore $0.27+0.495 = 0.765$-inch, which is the available draft. But, from Sect. 614 this is 80% of the total the stack must produce, so the total draft must be $0.765 \div 0.8 = 0.956$-inch. Adding 10% for leakage gives 1.0516-inch as the draft the stack must produce. From Table 8 a stack 100 feet high with gas temperature of 500 deg. and air temperature of 70 deg. will produce a draft of 0.61-inch, hence the net height of stack required is $100 \times 1.0516 \div 0.61 = 172$ feet. As the draft loss assumed for the boiler may be somewhat greater than actually occurs, a shorter stack might develop the given power, and it certainly would during cold weather. But in summer, and in case dirty coal is used, a stack of this height could not develop the full rating desired, hence a net height less than above determined cannot be advised. See Sects. 702 and 703.

653. Since the quantity of coal to be burned per hour is 2450 lbs. and we assumed 24 lbs. of gas per pound of coal, the maximum quantity of gas to be handled under the stated conditions will be 58,800 lbs. and since in Fig. 204 a boiler HP. equals 120 lbs. of gas, then $58{,}800 \div 120 = 490$ is the HP. of stack whose diameter is to be taken from the curves. A steel stack 57 inches, or brick stack 60 inches, in diameter will answer, and in any practical case a 60-inch stack would be used for either steel or brick.

654. Assume the same conditions as in the above example except that the boiler is to be operated at 200% of rating, and compute the height of stack required. This will require $2 \times 500 \times 3.25 = 3250$ lbs. of coal per hour, or a combustion rate of 32.5 lbs. per square foot of grate. Table 9 shows that the draft loss through the coal bed will then be 0.42-inch. The loss through boiler and breeching will be $0.22 \times 4 = 0.88$-inch; total $= 0.88 + 0.42 = 1.30$-inch, hence $1.3 \div 0.8 = 1.625$-inch, to which add 10% for leakage allowance, so that 1.7875-inch is the total draft the stack must produce. At this rating the temperature of the stack gases may be assumed as 550°, and with an air temperature of 70° as before, the draft in a 100 foot stack from Table 8 will be 0.644, hence $100 \times 1{,}7875 \div 0.644 = 278$ feet, is the net stack height necessary. To this must be added the distance from damper plate to floor level, which will range from 22 to 26 feet, hence the *total* stack height must exceed 300 feet above the firing floor.

655. To get the diameter, note that at 200% of rating the quantity of gas flowing will be at least one third greater than at 150% rating. But for the latter rating we needed the diameter corresponding to 490, or say 500 HP. in Fig. 204, hence $500 \times 1\frac{1}{3} = 667$ HP. will be the size now needed, and from the figure this is 64 inches for a steel stack, or 67 inches for a brick stack, and for practical purposes a 66-inch steel stack would be used, or a 68-inch brick stack.

656. The stack as above worked out is considerably higher than any competent engineer would consider when designing a plant using hand fired boilers, hence the only alternatives are to use a stoker (see Sect. 676), or a fuel requiring less draft than semi-bituminous coal, if it can be got, or to select a boiler section of such width that the grate surface can be considerably increased.

657. Suppose we increase the grate surface to 125 sq. ft., being in ratio of 40 sq. ft. of heating surface to one of grate surface. Recomputing the case for these conditions, the combustion rate per sq. ft. will now be 26 lbs., and the draft necessary to push the air through will from Table 9 be 0.3-inch, while the boiler and breeching loss will be 0.88 as before, hence the total will be 1.18-inch, and $1.18 \div 0.8 = 1.475$-inch is the total draft, to which add 10% leakage allowance, then 1.6225-inch is the draft the chimney

must produce, hence $100 \times 1.6225 \div 0.644 = 252$ feet is the net height needed. Thus we can in this way decrease the height by $278 - 252 = 26$ feet, which is not much, and if ground is valuable the increased space taken up by the wider boilers may be worth more than the extra cost of the higher stack. In either case, operating hand fired furnaces efficiently at such high combustion rates is not easy, and is not to be recommended. Again, if large grate surface be installed so as to permit operating at such high ratings, there may be considerable loss by carrying thinner fires when the boiler is operated at lower ratings, hence it is questionable whether the increased grate surface is to be recommended in any case where economy is important.

658. By Using a Coal Requiring Less Draft we can reduce the stack heights somewhat. Thus, assume that while using 100 sq. ft. of grate surface, and operating at double rating we change to bituminous slack coal, keeping all other conditions the same. Consider this coal as having 13,000 B. T. U. per pound as fired, and that 3½ lbs. will produce a boiler HP. We will then have to burn 3,500 lbs. per hour, or 35 lbs. per sq. ft. of grate. From Table 9 this will need 0.34-inch of draft to force the air through the coal. The draft through boiler and breeching will be 0.88 as before, hence the total at the stack base will be $0.88 + 0.34 = 1.22$-inch, and the stack must produce $1.22 \div 0.8 = 1.525$-inch, to which add 10% leakage allowance, so the total will be 1.6775-inch. Therefore $100 \times 1.6775 \div 0.644 = 261$ feet net height, as against 278 feet needed for semi-bituminous coal, yet this height is also prohibitive.

659. Another way of reducing the stack height is to make the draft loss in the stack less than 20% of the total produced. How that can be done will now be shown.

660. Relation Between Friction Loss and Stack Diameter When the Gas Quantity is Constant. The draft lost in a stack by friction of gas against the walls is computed by Chezy's formula, which may be found in Kent's *Pocket Book* and similar works, and if the weight of gas flowing be constant this formula shows that the frictional loss varies inversely with the fifth power of the stack diameter.

661. Application. Of the sundry schemes above tried that in Sect. 657 gives the lowest height, 252 feet, of which 80%, or say 202 feet, is needed to force the gas to the chimney, hence that cannot be reduced. The remainder, 50 feet, creates the draft to drive the gas through the stack when the stack draft loss is 20% of the total produced. The only opportunity to reduce the height is to cut down this 50 feet by increasing the stack diameter to diminish the draft loss in the stack. Assume that this loss is to be halved, and let x be the diameter of stack needed to do this. It was computed in Sect. 655 that a 64-inch steel stack was necessary under the conditions there assumed, hence from the above

$$x^5 : 64^5 = 2 : 1$$

hence $x = 73.5$ inches.

But as steel stacks vary in diameter by 6-inch steps a 78-inch stack would have to be used, so the increased diameter further reduces the draft loss, so let y equal the denominator of the fractional part of the 50-foot length which is to be retained (*i. e.*, y takes place of 2 in the above equation), then

$$78^5 : 64^5 = y : 1$$

hence $y = 2.688$, therefore $50 \div 2.688 = 18.6$ feet, which will produce the draft necessary to force the gas through the stack; the net height will then be $202 + 18.6 = 218.6$ ft. and as the damper plate will be 22 feet or more above the floor the total stack height will be 240 feet or more. As a matter of fact, about 10 feet more must be added, because this increase of stack diameter augments the stack surface over 12%, and this cools the gases in proportion (see Sect. 670), which decreases the draft, hence the necessity for the above addition, in consequence of which the net height will be 228 feet and the gross height 250 feet. The extra cost of the increased diameter will about nullify the saving in height, so this scheme is futile, and the resulting stack height is prohibitive.

662. With Hand Firing, only one other method of using natural draft and reducing the stack height remains. That is to increase the baffle openings or size of gas passes sufficiently to reduce the draft loss through the boiler itself. Some manufacturers do that and lay great stress on the fact that *their boilers do not need high stacks*, but the argument is unsound as shown in Sect. 291. Of the various draft losses listed in Sect. 612 the *only one which produces steam* is the loss through the boiler itself, hence to decrease this is equivalent to "saving at the spigot and losing at the bung," and must be summarily condemned. Therefore, when a salesman claims that the draft loss in his boiler is very small, he is unconsciously admitting that such boiler is poorly designed, and cannot get a high rate of

heat transmission to the water, hence has neither high efficiency nor capacity.

663. The coals assumed in all the above cases are of very high grade, and in many places such are not now obtainable. Hence on the average poorer coals would have to be assumed, and for these the draft loss through the fire would be still greater, therefore higher stacks would be necessary. *When fixing the stack height the liability of having to burn poor fuel should always be considered, and the height made sufficient to meet such emergency.*

It is to be further noted that in the above cases the breeching was short and direct. If long and crooked breechings had been asumed the consequences would have been as shown in Sects. 622 to 629 and the stack heights would have figured out 20 to 50 feet higher, and thus have made a bad matter even worse.

664. From all of which it follows as to boilers that are hand fired:—

(a) That the amount of grate surface, the kind of fuel to be burned, and its combustion rate, must all be taken into account when computing the stack height.

(b) That even when burning high grade coal it is impracticable to operate hand fired boilers with natural draft at over 150% of rating if the boilers are designed with long gas travel which is necessary for even reasonable fuel efficiency. See Sect. 662.

(c) That conversely, boilers which have small draft loss and can operate with short stacks are fuel wasters.

(d) That if over 150% of rating is wanted, the only way to avoid installing stacks of excessive height is to use induced draft, or to abandon hand firing and resort to forced draft stokers, for which see Sect. 676 and following.

(e) To develop 50% above rating with a highly efficient and properly baffled water tube boiler, a minimum net stack height of 170 feet for semi-bituminous coal, and 155 feet for bituminous coal should be provided, and higher will be needed if the coal is dirty or of very low grade. For high altitudes an increase is necessary, for which see Sect. 698.

(f) If long or crooked breechings are used, the stack height must be increased a sufficient amount to compensate for the draft loss in such breechings.

(g) If an economizer is used, a similar increase in the stack height must be made.

For burning oil, gas, wood, etc., shorter stacks may suffice, and the method of computing them is given in Sects. 687 to 697.

665. Minimum Stack Heights. It follows that even if boilers are hand fired, the chimneys must be high if *even a reasonable* overload capacity is desired. This must be clearly recognized, because of the multitude of short stacks visible everywhere in manufacturing districts, and the mistaken impression that they are sufficient because so often used. They are relics of the days when boilers were mostly of the return tubular design, with large flues, big grate areas in proportion to the power to be developed, slow combustion rates, and high flue gas temperatures, *because coal was then cheap!* It is not uncommon to find in such plants breeching temperatures of 700° to 800° and over, and the fuel such plants have wasted will aggregate an enormous total. With modern water tube boilers operating at high ratings and greatly increased economy, high stacks are essential, since the more economical a boiler is, the lower the temperature of the flue gas, and the lower this temperature the less draft it will produce, hence the higher the stack must be. C. L. Hubbard, in *American Electrician,* March, 1904, says:—"For plants of 700 to 800 HP. or over, the chimney should not be less than 150 feet high, regardless of the kind of coal to be used," and that is good advice if by this he means *net* height. Gebhardt, p. 294, suggests exactly the same thing.

The burning of pulverized coal has developed the fact that the fine flying ash produced by this process is liable to create a nuisance unless the stack is of sufficient height to scatter this material over so wide an area that it does not accumulate anywhere to a degree that is objectionable. It appears at present that a stack height of 200 ft. is probably the lowest that can be depended on, and for large installations heights of 250 to 300 feet are being proposed.

666. Consequences of Deficient Stack Height. The quantity of air necessary for proper combustion cannot be pushed through the fuel, hence the fire is dull and smoky, and the fuel is merely stewed or distilled instead of burned. Large quantities of volatile combustible pass away unburned, so that neither capacity nor efficiency can be got.

If the stack is deficient, better results can always be got by firing *only as many boilers as the stack can serve properly,* and these will pro-

duce more steam at less fuel cost than if more boilers are fired and proper combustion prevented. See Sect. 674.

667. Maximum Stack Heights. If the stack height is to be fixed purely from draft considerations instead of to comply with local ordinances as to the height at which the gas must be delivered, there is an economical limit of height as to cost. On this Gebhardt, *Steam Power Plant Engineering*, p. 294, says:—"Natural draft greater than 1.5-inch of water is seldom necessary and higher intensities can be obtained much better by forced or induced draft. This limits the height of chimney to about 225 to 250 feet." As will later appear, it is far better to discard hand firing and use stokers which reduce the stack height and give higher capacity and efficiency. See Secs. 183 to 187.

668. Stacks for Tall Buildings. These must deliver the gas above the building, and the great height may therefore produce an excessive draft. In such case Gebhardt, p. 291, says:—"The diameter is made very small so that a considerable portion of the pressure drop will occur in the stack and breeching, otherwise the draft will be excessive even with a throttled damper." This can be overcome by placing a supplementary damper in the stack itself, and the writer also suggests an air inlet valve in the stack base which can be adjusted to regulate the draft by admitting cold air.

669. Such cases give an excellent opportunity for developing higher efficiency than possible in the average plant, because with such strong draft the boilers can be baffled very much closer than usual, and the gas passages be made longer. This is conducive to economy. "A boiler that has its heating plates (surface) arranged in such a way that the gas passages are long and of small cross section is more efficient than a boiler in which the gas passages are short and of large cross section."—Bulletin 18, Bureau of Mines, p. 24.

670. Insulating Stacks and Breechings. These lose heat by radiation, conduction and convection, precisely as does a steam pipe. This may seriously affect the draft, and to prevent that steel stacks are often lined with brick. A more serious cause of loss is the cooling due to long breechings, and these should certainly be well covered if good work is expected. The more efficient the boilers, the cooler the gases, hence the more necessary to apply such covering. Data as to the rate of cooling in such cases are lacking. Gebhardt, p. 282, says:—"A common rule is to allow a drop of 80° per 100 feet of unlined steel stacks and 40° for brick or lined steel chimneys. These values are too high for tall chimneys of large diameter and too low for small short stacks. Another rule is to allow 5% to 10% of the theoretical maximum static draft as the pressure drop due to the cooling action. Both rules are purely arbitrary and may give results far from the truth." All of this evidences that stack design is a complicated matter which should not be entrusted to novices.

671. Stack Formulas. Many have been published, but few are reliable, and not even these unless used with care. An interesting collection of such is given by Gebhardt, p. 297, but of these we shall reproduce but one.

672. Kent's Formula. In 1884 Wm. Kent published a table of stack capacities based upon an empirical formula he deduced from a study of certain stacks which had given good results, and this table has been extensively used since and is so often referred to that it is reproduced here, and will be useful for certain purposes if properly interpreted and applied. He assumes that a layer of gas two inches thick covers the inside surface of the stack and is inert, hence the net area of stack is equal to the total area minus this 2-inch layer.

Let A=actual area of cross section, sq. ft.
E=effective area of cross section, sq. ft.
H=*net* height of chimney in feet.
HP.=rated boiler horse power.

Then Kent's formula is

$$E = A - 0.6(A)^{\frac{1}{2}}$$

$$H = \left(\frac{0.3\ HP.}{E}\right)^2$$

Table 12 from Gebhardt's *Steam Power Plant Engineering*, p. 298, gives the stack dimensions according to Kent's formula in convenient shape for quick reference. The table is based upon 5 lbs. of coal per boiler horsepower per hour, to provide for burning poor coal, and upon 24 lbs. of air being admitted per pound of coal, so that the stack can handle 120 lbs. of gas per *rated* HP. of boiler and thus operate the boiler up to 50% overload.

Since this table appeared conditions have so greatly changed as to the kind of boilers in general use, higher combustion rates, and frequent use of stokers, that it is not safe to depend upon it other than to get quickly the *approximate* dimensions of a stack when *bituminous, semi-bituminous, or lignite coals* are burned, the grate

TABLE 12.

NET HEIGHT OF CHIMNEYS FOR HAND FIRED BOILERS ACCORDING TO KENT'S FORMULA.

Diam. Inches.	Area (a) Sq. Ft.	Effective Area $E = A - 0.6\sqrt{A}$ Sq. Ft.	Height of Chimney.													Equivalent Sq. Chimney Side of Sq. $\sqrt{E}+4$ Inches.
			50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	225 ft.	250 ft.	300 ft.	
			Commercial Horse Power of Boiler.														
18	1.77	.97	23	25	27	29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	16
21	2.41	1.47	35	38	41	44	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	19
24	3.14	2.08	49	54	58	62	66	.....	.....	.....	.....	.....	.....	.....	.....	.....	22
27	3.98	2.78	65	72	78	83	88	.....	.....	.....	.....	.....	.....	.....	.....	.....	24
30	4.91	3.58	84	92	100	107	113	119	.....	.....	.....	.....	.....	.....	.....	.....	27
33	5.94	4.48	.....	115	125	133	141	149	156	.....	.....	.....	.....	.....	.....	.....	30
36	7.07	5.47	.....	141	152	163	173	182	191	204	.....	.....	.....	.....	.....	.....	32
39	8.30	6.57	.....	.....	183	196	208	219	229	245	.....	.....	.....	.....	.....	.....	35
42	9.62	7.76	.....	.....	216	231	245	258	271	289	316	.....	.....	.....	.....	.....	38
48	12.57	10.44	.....	.....	.....	311	330	348	365	389	426	.....	.....	.....	.....	.....	43
54	15.90	13.51	.....	.....	.....	.....	427	449	472	503	551	595	.....	.....	.....	.....	48
60	19.64	16.98	.....	.....	.....	.....	536	565	593	632	692	748	.....	.....	.....	.....	54
66	23.76	20.83	.....	.....	.....	.....	.....	694	728	776	849	918	981	.....	.....	.....	59
72	28.27	25.08	.....	.....	.....	.....	.....	835	876	934	1,023	1,105	1,181	1,253	.....	.....	64
78	33.18	29.73	.....	.....	.....	.....	.....	.....	1,038	1,107	1,212	1,310	1,400	1,485	1,565	.....	70
84	38.48	34.76	.....	.....	.....	.....	.....	.....	1,214	1,294	1,418	1,531	1,637	1,736	1,830	2,005	75
90	44.18	40.19	.....	.....	.....	.....	.....	.....	.....	1,496	1,639	1,770	1,893	2,008	2,116	2,318	80
96	50.27	46.01	.....	.....	.....	.....	.....	.....	.....	1,712	1,876	2,027	2,167	2,298	2,423	2,654	86
102	56.75	52.23	.....	.....	.....	.....	.....	.....	.....	1,944	2,130	2,300	2,459	2,609	2,750	3,012	91
108	63.62	58.83	.....	.....	.....	.....	.....	.....	.....	2,090	2,399	2,592	2,771	2,939	3,098	3,393	96
114	70.88	65.83	.....	.....	.....	.....	.....	.....	.....	.....	2,685	2,900	3,100	3,288	3,466	3,797	101
120	78.54	73.22	.....	.....	.....	.....	.....	.....	.....	.....	2,986	3,226	3,448	3,657	3,855	4,223	107
132	95.03	89.18	.....	.....	.....	.....	.....	.....	.....	.....	3,637	3,929	4,200	4,455	4,696	5,144	117
144	113.10	106.72	.....	.....	.....	.....	.....	.....	.....	.....	4,352	4,701	5,026	5,331	5,618	6,155	128

NOTE: This table applies to *bituminous coal only,* and must be used with caution, for which see Sect. 673. *When properly used* it is supposed to give dimensions of stacks to operate the boilers up to 150% of rating, and each HP. of capacity in the table be able to take care of 5 lbs. of coal, or 120 lbs. of gas per hour. But carefully note Sect. 673.

surface very large, and the breechings are short and direct. Such approximation should always be checked by the more reliable methods already given. See next Section.

673. Caution as to Using Any Stack Formula or Table. Serious and costly mistakes have resulted from use of these formulas or tables without proper understanding of their limits. Thus, note Sect. 664(a), then refer to Sect. 652 in which it was computed that a stack of 172 ft. net height is necessary. Of this, 34.4 ft. are needed to drive the gas through the stack, and we might change that dimension as shown in Sect. 661, but we *cannot change* the other 137.6 ft. needed to force the gas from ash pit to the stack. It was computed that a stack 60 inches diameter is necessary, hence referring to Table 12 it will be seen that a stack 90 feet high will be sufficient to operate up to 50% of overload, a boiler rated at 500 HP. In the given case this height would fall 47.6 feet short of being able to bring the gas to the stack, hence would prove an utter failure! Whereas if it were made 175 ft. high the table says it is sufficient to operate a 748 HP. boiler 50% overload, *which it certainly could not do* if applied to a modern water tube boiler baffled for high efficiency.

The explanation lies in the fact that when Kent issued this formula combustion rates were small, and boiler efficiency of minor importance. Therefore:—*Never rely upon any stack table or formula without checking the results by taking into account every factor in the manner already shown in this book.*

674. Variation in Available Draft When Boilers are Cut In or Out. Assume that by the preceding methods the dimensions had been ascertained for a stack to serve 5 boilers, of any given HP. and at a specified rate of overload, and to produce an available draft (Sect. 613) of say 0.72-inch when so operating. If now one boiler be cut out, the amount of gas flowing through the stack will decrease, and the available draft will therefore increase. It is easy to determine the amount of such increase. As the stack was figured on basis of losing 20% of the total draft in friction (Sects. 616 and 646), it follows that when operating 5 boilers the *total draft* produced by the stack will be $0.72 \div 0.8 = 0.9$-inch, and the draft loss in stack will be $0.9 - 0.72 = 0.18$-inch, of water.

Let x=the loss when only 4 boilers are operating, then, since the quantity of gas varies directly as the number of boilers, and the draft loss in stack as the *square* of the quantity of gas,

$x : 0.18 = 4^2 : 5^2$

or $x = 0.1152$, from which

Available draft $= 0.9 - 0.1152 = 0.7848$-inch.

If after the plant was completed it were found necessary to add another boiler to it, and connect it to the same stack, the increased quantity of gas will reduce the available draft when all boilers are running. Since 6 boilers are now operating the stack loss x will be

$x : 0.18 = 6^2 : 5^2$, hence

$x = 0.2572$, so that

Available draft $= 0.9 - 0.2592 = 0.6408$-inch, which is insufficient to operate *all of the 6 boilers at once,* up to the same degree of overload possible when only 5 boilers are steaming.

This clearly proves that the installation of additional boilers is futile, without providing a corresponding stack capacity to operate them. It may even happen that by adding additional boilers the amount of steam produced may be even less than before! The reason is that the decrease of draft may so interfere with the combustion under *all* the boilers that the fires are dull and smoky, and merely distil the coal, instead of burning it completely. See Sect. 666.

675. To Find What Available Draft An Old Stack Will Produce. Occasionally one finds a stack already built, and desires to attach to it certain boilers, if the draft will be sufficient to operate them. The following will show how the draft can be computed.

Assume that we found a steel stack 90 inches diameter, and 160 feet in *net* height, and that we desired to connect to it three boilers rated 400 HP. each, to operate up to double rating, when stoker fired, and that not less than 0.75-inch available draft were necessary. Further assume that the gas temperature entering the stack is 550 deg., and that the stokers will produce 70 lbs. of gas per hour per boiler HP. developed. In any actual case, of course, these data would have to be first ascertained according to the conditions. See Sect. 681(b).

If the average air temperature be assumed as 60 deg. then from Table 8 the total draft this stack will produce is 1.074-inch.

From Fig. 204 this stack is rated at 1600 HP. and when losing 20% of the draft it produces it will be passing $1600 \times 120 = 192{,}000$ lbs. of gas per hour, and the draft loss in the stack will be $0.2 \times 1.074 = 0.2148$-inch.

The three boilers above named, will at double rating under the above assumptions produce $2\times3\times400\times70=168{,}000$ lbs. of gas.

Let x be the stack draft loss when this quantity of gas is passing, then

$x : 0.2148=168^2 : 192^2$, hence

$x=0.1645$, hence

Available draft=1.074—0.1645=0.9095-inch, which is more than sufficient.

But, if 5 such boilers were to be connected to this stack, the stack draft loss x would be

$x : 0.1645=5^2 : 3^2$, hence

$x=0.4569$, hence

Available draft is 1.074—0.4569=0.6171-inch, which is clearly too small.

If 4 boilers be attached, a similar computation will show that the draft loss will be 0.292-inch, hence the available draft will be 0.782-inch, which is sufficient, hence 4 boilers may be installed with safety.

Regardless of the size of the stack, and the number of boilers, the case can be computed in exactly the same way if the necessary preliminary data are known.

Stacks for Stoker Fired Boilers.

676. By using a good stoker the quantity of excess air can be reduced, and frequent opening of the firing doors be avoided. This increases the economy of the plant. Further, poorer fuels can be utilized, which also effects a saving. For larger plants considerable saving in labor can also be effected which at the present time is as important as saving fuel.

677. Kind of Stokers. The two great divisions are:—(a) Over-feed or surface-feed types; (b) Under-feed types. In the first the fresh coal is spread over the fuel bed, hence distillation proceeds as in hand firing, and the volatile matter must be burned in the same way, by admitting air above the fire. Under-feed stokers, by means of screws, plungers, or some equivalent, push in the coal from below, and it is later forced upward by fresh incoming fuel, and overflows out on to the grates.

678. A much more important division for our purpose is, (c) Stokers which operate by natural or induced draft which drives the air through the fuel bed as in hand firing, and (d) Stokers operated by forced draft applied in the ash pit, and of such intensity as to supply just the draft necessary to push the requisite amount of air through the fuel, without causing any pressure inside the furnace above the fuel bed.

679. Over-Feed Stokers usually belong to the first division, hence with these in use the stack must be made of sufficient height to burn the necessary fuel, just as in hand firing. As one purpose of a stoker usually is to give a greater capacity than hand firing, it is evident that for such cases, if the quantity of air used per pound of fuel is the same as with hand firing, the stack must be even higher than before since it depends upon the combustion rate and amount of gas produced. A good stoker of any class, however, uses less air per pound of fuel than hand firing, and this reduces the excess chimney height needed at the higher ratings.

The kind of fuel, combustion rate, and quantity of gas produced being settled, the stack dimensions can be computed as shown in Sects. 651 to 662.

680. With Under-Feed Stokers the conditions as to draft are greatly changed. In these, air is forced through the fuel bed by a fan, hence the air pressure and volume, the amount of coal burned, and the amount of steam being generated, can all be regulated at will.

681. Assume that the 500 HP. boiler with 100 sq. ft. of grate surface, as used in Sect. 651, had grates 8 feet deep, then the furnace width would be 12 feet 4 inches. In any actual case this width would be 12 feet 6 inches in most boilers. Into this width can be installed a 7-retort under-feed stoker which can continuously burn per retort 450 lbs. or more of coal per hour, and in emergencies it can burn 800 lbs. per hour for a two hour peak load, but cannot maintain that rate if the ash contains clinkers. Then, at the normal rate the coal burned will be $7\times450=3150$ lbs., and at the highest rate it will be $7\times800=5600$ lbs. In such cases a poorer grade of coal is usually purchased, so let us consider that 4 lbs. of such coal will be needed per boiler horsepower. In that event, these amounts of coal will develop 787 and 1400 HP. respectively, or an output of 157% and 280% of rating. We will compute the stack heights necessary for these two cases. Before doing so, we must clearly understand two important things:—

(a) In this case all the stack has to do is to produce enough draft to transport the gases from over the fire and into and through the boiler, breeching and stack, because the fan now supplies the pressure necessary to force the air through the fuel bed. (b) A good stoker should burn a pound of coal with not over 50% excess

air, or 18 pounds, instead of 24 or more as used in hand firing, and many use much less. But, the draft loss of 0.2-inch, or other amount assumed, through the boiler was based on operating at rating with hand firing and 24 lbs. of air per pound of coal, hence with the reduced air supply the loss *at rating* when the stoker is operating will be only $0.2\times(18\div24)^2=0.1125$-inch (see Sect. 634), and if the boiler and breeching loss together were 0.22 as before assumed for hand firing, that will now be $0.22\times(18\div24)^2=0.12375$-inch. Hence, at 157% of rating the boiler and breeching loss will now be $0.12375\times(1.57)^2=0.305$-inch, and at 280% of rating this will be $0.12375\times(2.8)^2=0.97$-inch. In the first case we may assume the temperature of the stack gas as 550°, and the air temperature 70° as before, and the stack must produce a draft of $0.305\div0.8=0.381$-inch, to which add 10% for leakage, hence the final draft to be produced by stack is 0.4191-inch. Therefore $100\times0.4191\div0.644=65$ feet, is the net height necessary.

682. When the boiler is operating at 280% of rating the stack temperature may be taken as 600°, and the total draft must be $0.97\div0.8=1.2125$, to which add 10% for leakage, hence the final stack draft must be 1.3338-inch, hence the net stack height will be $100\times1.3338\div0.69=193$ feet. Assuming that the height from floor to damper plate is 25 feet, the total height above floor line for the two cases will be 90 and 218 feet. The former is lower than would be tolerated in any city, and the latter is entirely reasonable in any plant where high ratings are wanted, and shows that when using such stoker a stack of 225 ft. total height will be sufficient to operate the boilers up to about 300% of rating if the boilers themselves can stand such rating without burning their tubes.

The amount of gas to be handled being known, the stack diameter can be computed as already shown in Sect. 653.

683. All this clearly points out the great advantage of using forced draft of sufficient pressure to drive the air through the fuel, and relieves the stack of that part of the work. By so doing, high boiler capacities can be developed with stacks of reasonable height, poorer fuel can be successfully used, and the steam output controlled more rapidly than by hand firing. All of this confirms what is said in Sects. 183 to 188.

684. Caution as to Use of Forced Draft in the Ash Pit. It is a common error to suppose that by using forced draft in the ash pit *the stack height can be reduced* far beyond what is really possible, because it is assumed that such draft can assist in pushing the gases through the boiler. The only way in which this can be done with safety is by means of a closed stoke-hold system such as is used aboard ships. Here the fire room is an enclosed apartment in which by means of a fan the air pressure is kept greater than that of the atmosphere, hence when the fire doors are opened the air rushes *inward,* and thus can help to force the gases through the boiler. But, in land plants with open fire rooms at atmospheric pressure, this cannot be done, since the moment the air pressure in the furnace exceeds that of the atmosphere it will cause flames to issue into the room through every crevice around the doors, etc., and if these doors are opened a sheet of flame will be projected across the room. In any event, smoke and gas will pour out through every opening, etc., and render the fire room uncomfortable or even uninhabitable by the operatives. Consequently *there should always be enough vacuum in the furnace to cause air to flow inward* when the doors are opened, hence the stack must always be of sufficient height, or the induced draft apparatus of sufficient capacity, to move the gases from the surface of the fire to the final exit from the stack. It is desirable to have a vacuum of at least 0.06-inch of draft over the fire, and 0.1-inch is better. "Where the furnaces are operated under a suction which causes the cool air to be drawn inward through the brickwork there is a cooling effect which serves to prevent overheating, whereas if they are operated under a pressure there is a tendency for the hot gases to leach outward and overheat the brickwork. The difference between running with a slight suction of, say, 0.1-in. water column and a plus pressure within the furnace may make all the difference between successful operation and having a lot of trouble."—*Boiler and Furnace Economy*, in *Mechanical Engineering*, December, 1921.

"There are many forced draft plants in operation whose stack dimensions are so poorly proportioned, or whose breeching and damper openings are so poorly designed, that the facilities are wholly inadequate for carrying out of the furnace the quantities of heat required to satisfy the demands for steam. Today, most every one knows that the shortcomings of a stack or breeching cannot be offset through the installation of a forced draft outfit, and that the first

sign of failure of such an attempt is a failure of the brickwork. This is the old story of bottled-up furnace heat, and in spite of the long numbers of years that this story has been told, the conditions arising therefrom are still with us in innumerable plants, needlessly destroying thousands of perfectly good brick."—S. S. Bulletin No. 2 of Laclede-Christy Co., St. Louis., Mo., November, 1921.

Lack of understanding of this simple fact has caused numerous failures in plants where forced draft was installed.

685. Balanced Draft. To overcome the danger above pointed out mechanical devices have been worked out whereby when forced draft is applied to the ash pit the pressure in the furnace will automatically be kept at that of the atmosphere or slightly less as above directed. This is known as "balanced draft" and equipment to produce it is extensively used.

686. Tables of Stack Sizes for Stoker Fired Boilers. Sundry such tables have been prepared, but none will be given here, because they are all based on assumptions or averages which may or may not apply in any given case. Their use is therefore liable to lead to error just as pointed out in Sect. 673, and *the only safe way is to compute the stack dimensions in the manner above shown, after taking into account all the factors entering the case.*

Stacks for Fuels Other Than Coal.

687. Stacks for Boilers Burning Oil. In this case there is no draft loss due to pushing the air through the fuel bed, as the burners inject the oil into the furnace after atomizing it into a fine spray practically equivalent to a gas. Further, the air per pound of fuel is much less than with coal, and by careful adjustment the air supply has been gotten down as low as 110% of the theoretical amount, and the use of 150% indicates inefficient firing. In consequence, the draft loss through boiler and damper often does not exceed 0.1-inch when the boiler is operating at rating, and 0.15-inch allowance is high, hence ample for any boiler unless its baffling system is unduly complicated. Accordingly, the loss should not exceed 0.3375-inch at 150% of rating; 0.6-inch at 200% of rating; 0.9375-inch for 250% of rating, and 1.35-inch at 300% of rating, and is often less than these allowances.

The stack areas can easily be computed from Fig. 204 as follows:—Fuel oil averages 18,500 B. T. U. per pound, and therefore 2½ lbs. of oil will produce a boiler HP. when operating at about 72% efficiency, which is low, as 75% should easily be got when operating with 50% excess air. Theoretically, 14 lbs. of air will be needed to burn one pound of oil with no excess, hence with 50% excess, 21 lbs. of air will be needed, to which add steam used for atomizing, and to cover this assume 22 lbs. of chimney gas are produced per pound of oil burned, hence $22 \times 2\frac{1}{2} = 55$ = pounds of gas produced per boiler horse power when burning oil with 50% excess air. Fig. 204 is based on 120 lbs. of gas per boiler HP., hence a given area of stack is good for 2.12 times as many *actually developed* boiler HP. when burning oil as shown in Fig. 204, in which provision is made for developing 50% more capacity than given in the HP. rating on the left hand side of the Figure. Conversely, to develop *actual* HP. ratings equal to those on left hand side of the figure, when burning oil, will require only 0.46 of the stack capacity as scheduled for coal in this Figure.

688. Example. Find the diameter of a steel stack to operate 1000 HP. of water tube boilers operating at 200% of rating, when burning oil with 50% of excess air. The boilers will be developing $2 \times 1000 = 2000$ HP., hence $2000 \times 0.46 = 920$ HP., which is the size to look for in Fig. 204, from which we find that a steel stack 72 inches, or brick one 76 inches in diameter will suffice.

To get the stack height, assume that the gas temperature is 550° and the air temperature outside is 70°, then from the above data the draft at the stack base must be 0.6-inch, hence the stack must produce $0.6 \div 0.8 = 0.75$-inch of draft. From the draft table a stack of 100 ft. high at these temperatures will produce a draft of 0.644-inch, hence $100 \times 0.75 \div 0.644 = 115$ feet, is the net height of stack needed, measured above the boiler damper plate.

689. In this case no allowance has been made for the leakage factor, because with the smaller intensity of draft used this will not be as great as usual with coal. If the construction is good, 5% allowance should be sufficient, hence 6 feet added to the above height would cover this item.

690. In precisely the same way it can be computed that to operate at 50% above rating, and with a breeching temperature of 500°, all other conditions being the same, a steel stack 63 inches diameter and 58 ft. net height would answer, and we would use the next larger commercial size, 66 inches in diameter. In any practical

case, a minimum height of 75 ft. would probably have to be used in city plant. For approximate estimates it is sufficiently accurate to assume that the stack diameters as in Fig. 204 are good for double the number of horse power as given for coal, and that a *net* stack height of 75 ft. is sufficient for 150% of rating; 125 ft. for double rating, and 200 ft. for triple rating. By increasing the diameter as shown in Sect. 661 the height can be somewhat reduced if desired.

neers, 1912, a paper entitled *Dimensions of Boiler Chimneys for Crude Oil,* in which the subject is treated with great elaboration, and tables are given for stacks serving boilers both with and without economizers, but before attempting to use these tables the context should be read carefully so that the proper use of these tables, and their limits, will be understood.

692. Table 13, reproduced from *Efficiency in the Use of Oil Fuel,* U. S. Department of In-

TABLE 13.

APPROXIMATE DIMENSIONS OF STACKS FOR OIL FUEL.

The *Net* Height is 12 ft. Less than Tabular Height.

Stack diameter, inches.	Height above boiler-room floor, feet.					
	80	90	100	120	140	160
	Nominal rated boiler horsepower.					
33	161	206	233	270	306	315
36	208	253	295	331	363	387
39	251	303	343	399	488	467
42	295	359	403	474	521	557
48	399	486	551	645	713	760
54	519	634	720	847	933	1,000
60	657	800	913	1,073	1,193	1,280
66	813	993	1,133	1,333	1,480	1,593
72	980	1,206	1,373	1,620	1,807	1,940
84	1,373	1,587	1,933	2,293	2,560	2,767
96	1,833	2,260	2,587	3,087	3,453	3,740
108	2,367	2,920	3,347	4,000	4,483	4,867
120	3,060	3,660	4,207	5,040	5,660	6,160

If the breechings are long or crooked, the additional draft loss caused by them can be taken into account precisely as shown in the cases when coal is burned.

691. Economizers are not often installed in connection with boilers burning oil, but if used the additional draft resistance caused by them must be taken into account. This can easily be done by obtaining from the manufacturer the draft loss caused by his equipment for any given conditions, and by adding this to the loss as above determined the total loss can be ascertained, and the stack height proportioned to suit.

Mr. C. R. Weymouth published in *Transactions of American Society of Mechanical Engi-*

terior, Washington, 1919, is based on Weymouth's tables, and relates to boilers *without economizers,* and with stacks located close to the boilers *with short and direct* connecting flues. The tabular values are *rated* boiler horse powers, and stacks of the dimensions given are assumed to be able to operate the boilers up to 150% of rating, when 50% excess air is used. The *net* stack height is the tabular height less 12 feet.

Comparing with this table the results worked out in Sect. 688, etc., it was there found that a steel stack 72 inches diameter by 115 ft. net height easily develops 2000 HP. Adding 12 ft. to get to same basis as in Table 13, the gross height will be 127 feet, and the tabular HP. cor-

responding is about 1700. Operating this 50% overload will produce 2550 HP., as against 2000 figured in Sect. 688. The difference is due to variations in the assumptions made, which is to be expected in work of this kind which involves so many fluctuating factors. The purpose always kept in view in this book is to observe the maxim "Safety first," and to present methods which produce results which are safe even under adverse conditions. Our allowance of 50% excess air is large, and if this be cut to 25%, which any competent operator can do, then a stack of the size above computed will prove ample for developing 2550 *actual* HP. or slightly more. See Sects. 701 to 703.

693. Stacks for Boilers Burning Natural Gas. The calorific value of natural gas varies greatly. Such data as we have show that a cubic foot of natural gas at 32° F. and atmospheric pressure contains 750 to 1120 B. T. U. To strike an average we have taken a gas of known composition and computed its heat value as 915 B. T. U. per cubic foot at the above named temperature and pressure, and further computed that the theoretical amount of air necessary to burn this will be 8.12 cu. ft. at 32° F. and atmospheric pressure. The weight of this air is 0.080728-lb. per cu. ft., hence the weight of 8.12 cubic feet will be 0.66-lb. Allowing 50% excess air, this figure will become 0.99-lb., so we will assume that 1 lb. of air will burn 1 cu. ft. of gas, containing an average of 915 B. T.U., which will evaporate 0.7-lb. of water from and at 212° with over 73% efficiency. Under these conditions about 50 cu. ft. of gas will develop one boiler HP., and to burn this quantity of gas 50 lbs. of air will be required.

694. The only practical difference between burning oil and gas is that the former, being liquid, must first be atomized, after which so far as combustion is concerned it acts like a gas, and the furnace arrangements for the two fuels will be practically the same, hence the size of the stacks for natural gas may be computed in exactly the same way as for oil, if the number of pounds of air needed to develop a boiler HP. when burning the gas is known. Since we have found this to be 50 lbs. for gas and 55 lbs. for oil, a stack computed for oil will serve equally well for gas, but have about 10% greater capacity for gas than for oil.

695. Stacks for Burning Blast Furnace Gas. Such gas is very dusty or dirty and needs large furnace volume as stated in Sect. 170. The usual method of proportioning the stack is to give it a net height of not less than 100 ft. in order to operate the boiler up to 150% of rating, and of a net height of not less than 135 ft. to develop 175% of rating. The diameters are then made as per Kent's formula, Table 12, corresponding to the respective heights and HP. to be developed.

A more accurate method is to compute the amount of gas which would have to be handled at the maximum rating to be developed, provided the boilers were hand fired, and add 15% to 20% to such gas volume as representing the quantity resulting when developing that boiler capacity when burning blast furnace gas. Then compute the stack height and diameter precisely as in Sects. 648 to 655. See *Steam Power from Blast Furnace Gas,* in *Power,* November 8, 1921. Or otherwise expressed, allow 92 to 100 lbs. of flue gas per each *actual* HP. to be developed, then proceed as before shown.

For burning such gas with high efficiency it is essential to install a burner which is designed to mix the gas and air thoroughly. Many plants use a very crude design for this purpose, hence secure poor results. Fig. 194 shows the installation of a burner which has produced excellent results with blast furnace gas.

696. Stacks for Boilers Burning Wood. The height of such stacks will depend mostly on the way the grates and furnace are arranged. If the grates are large, very little draft is needed, but the excess air supply will be great. Hutton, p. 28 of *Steam Boiler Construction,* says:—"A cord of wood can be burned per hour on 60 sq. ft. of fire grate surface," but evidently this depends on how much draft is supplied. He likewise says:—"Wood fuel requires ⅓ *more* grate surface and ⅔ more space in the furnace than is required for coal, for equal generation of steam." A cord of hickory weighs about 4470 lbs., while a cord of yellow poplar weighs about 2500 lbs., and other woods range between these, hence burning a cord on 60 sq. ft. of grate means 75 to 42 lbs. of wood burned per sq. ft. per hour. Hutton (p. 449) further says:—"With a fire 2 ft. thick, and a draft of from ¼ to 1-inch, from 25 to 80 lbs. of wood may be burnt per sq. ft. of grate surface per hour."

697. Our experience confirms Hutton's view as to need of large combustion space, but as he evidently refers to the small combustion spaces formerly used for coal we consider that a furnace volume as determined for coal by applying the

principles laid down in Sects. 156 *et seq.*, will be of ample size for wood. But, our observation has clearly indicated that the grate surface for wood should not be *more* than needed for American coals, but less, and that very thick fires are necessary to prevent a large excess of air from entering. To get the best results the furnace walls should be battered to form a truncated V, with the grates at the bottom, and their width should be about ⅔ of what would be used for coal. The wood should then be piled on these grates to a depth of 3 ft. or more, and the freshly fired logs crush down those which have been partly burned, thus filling the bottom of the furnace with closely packed charcoal which prevents the large air leakage certain to take place when the wood is piled only moderately deep, with large interstices between the logs. With a furnace so arranged, very economical results can be got, and a stack 120 to 140 ft. high with diameter per Kent's rule, Table 12, will usually be sufficient. With large grate surfaces shorter stacks can be, and frequently are, used, but the air supply is then excessive, and the waste is large, hence such stacks cannot be advised. For stacks serving boilers fired with wet sawdust, hogged fuel, or similar materials with high moisture content, a strong natural draft seems better than forced draft because it does not lift the fuel off the grates. For such cases stacks 165 to 175 ft. high have given good results. Any excess draft when the stack is high can be checked by proper use of the damper, whereas for insufficient draft the only remedy is to carry a thinner fire, which means excess air.

TABLE 14.

CORRECTION FACTORS APPLYING TO STACKS LOCATED ABOVE SEA LEVEL.

Altitude in Feet Above Sea Level	Barometer Reading Inches	R Relative Gas Volume	$\frac{1}{R}$ Relative Draft	$R^{\frac{2}{5}}$ Ratio Stack Diameters	R^2
0—Sea Level.....	30.00	1.000	1.000	1.000	1.000
1,000.....	28.92	1.037	0.964	1.015	1.075
2,000.....	27.88	1.076	0.929	1.030	1.158
3,000.....	26.88	1.116	0.896	1.045	1.245
4,000.....	25.91	1.158	0.864	1.060	1.341
5,000.....	24.98	1.201	0.833	1.076	1.442
6,000.....	24.08	1.246	0.803	1.092	1.553
7,000.....	23.22	1.292	0.774	1.108	1.669
8,000.....	22.38	1.340	0.746	1.124	1.796
9,000.....	21.58	1.390	0.719	1.141	1.932
10,000.....	20.80	1.442	0.693	1.158	2.079
11,000.....	20.05	1.496	1.668	1.175	2.238
12,000.....	19.34	1.551	0.645	1.192	2.406
13,000.....	18.65	1.609	0.622	1.210	2.589
14,000.....	17.97	1.669	0.599	1.227	2.786
15,000.....	17.32	1.732	0.577	1.246	3.000
16,000.....	16.70	1.796	0.557	1.264	3.226

698. Modification of Stack Dimensions Required by Altitude. Regardless of the altitude at which a plant may be situated, it will take the same number of *pounds* of air to burn a pound of any given fuel. But, as the altitude increases, the air becomes more rarified, hence weighs less per cu. ft., therefore more cu. ft. must pass through the fuel in order to supply the same weight of air. Also, the draft at the base of the stack of given height will decrease as the altitude is increased, therefore the stack dimensions must be increased to compensate for these fac-

tors. The increase can be computed as follows:—Assume that the mean barometer reading at sea level is 30 inches of mercury, or 14.7 lbs. absolute per square inch. Get the mean barometer reading at the altitude where the plant is situated, and find the ratio of these by dividing the barometer reading at the altitude into that at sea level, and call the quotient R. Thus, at a point where the barometer reading is 25 inches, R will be 30÷25=1.2. Compute the dimensions of a stack as needed at sea level, then for the altitude multiply the cross section of the stack (and the grate area as well) by $R^{2/5}$ and the height by either R or R^2. There is some difference of opinion as to whether R or R^2 is the proper multiplier in this case. The first solution of this problem was published in *Stirling*, p. 176, and in this the multiplier is given as R, which we have long accepted and used with success. Mr. Weymouth, in the paper above cited, Sect. 691, gives R^2 as the proper multiplier together with his reasons therefor, which do not seem conclusive. *Steam Boiler Engineering* (*Helios*, 27th Edition), p. 193, recommends the ratio $R^{1.3}$ for heights, and $R^{0.6}$ for diameters. As far as our personal experience goes in plants located in many parts of the Rockies, stack heights determined by using ratio R have given good satisfaction in places which are not blanketed by surrounding mountains.

699. Table 14 gives the values of these multipliers for the various altitudes, together with other data pertaining thereto, all computed from a formula furnished by the U. S. Bureau of Standards, Washington, D. C., for a mean temperature of 50 deg. Fah., which is assumed as a base because the mean at an altitude is lower than at sea level. The atmospheric pressure in pounds per square inch can be got by dividing the barometer reading by 2.04.

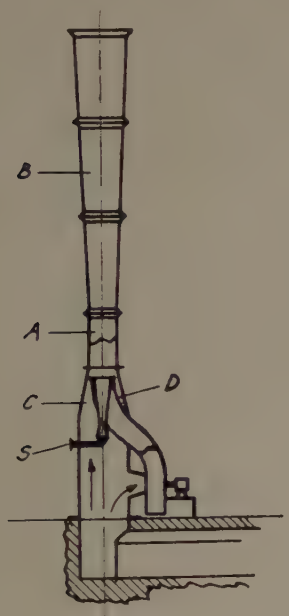


FIG. 206

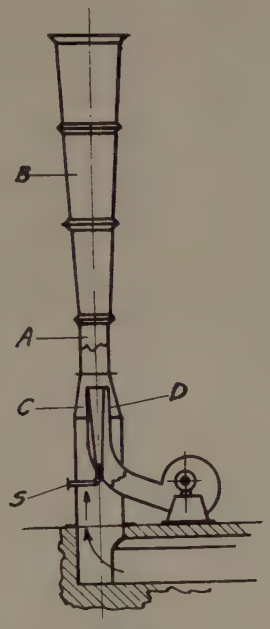


FIG. 207

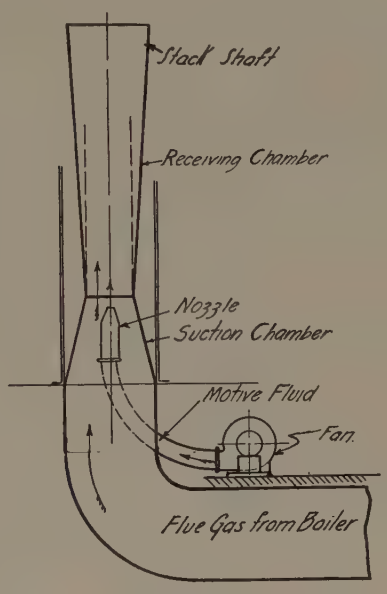


FIG. 208

EVASE, PRAT, OR VENTURI EJECTOR STACKS

The table shows that practically no increase in height is needed for altitudes less than 1500 feet, and none in area for less than 3000 feet, but that above one mile in altitude, especially if R^2 be used as the multiplier, the heights become such that induced draft apparatus will probably be preferable to installing a chimney of sufficient height to produce the required draft, owing to the large difference in cost.

700. Evasé, Prat or Venturi Stacks. This design originated in Europe and has some unique features. Figs. 206 to 208 adapted from *Venturi Stacks* in *Combustion*, April, 1922, illustrate the method of operation. Fig. 206 shows that the gas from the boiler flows into a so-called Venturi tube, consisting of two conical elements joined at the smallest diameter as shown. Below this throat is a nozzle through which passes a jet of air or gas causing an ejector effect which can be arranged to produce a vacuum of 3 or 4

inches or more in the breeching below, thus providing an induced draft apparatus.

In practise, the "motive fluid" for the jet may be either air from outside, or a portion of the chimney gas itself. Fig. 207 shows the equipment arranged for the former, in which case the fan handles only air of atmospheric temperature, hence is very durable, but the injected cold air lowers the temperature of the mixture, hence reduces the resulting draft. This objection is overcome by drawing from the breeching sufficient hot gas to operate the jet, in which case the arrangement is as in Fig. 208. In these two figures A is the contracted neck, B the exit chamber or stack proper, C the lower funnel-shaped portion, and S an auxiliary or emergency steam jet blower for use if the fan stops, or in case of a high peak load requiring a greater draft than the jet of gas can produce.

The distinguishing difference between this method and the usual induced draft arrangement is that in the latter all of the hot gas must pass through the fan, while in the former the fan has to handle only a fraction, say from 50% to 20% of the total gas volume according to the pressure produced by the fan and the total stack draft wanted. Therefore the power required for the fan in the Evasé system may be only 15% to 25% of that required for an induced draft equipment, which is an important advantage, since the fan for these stacks may use only 0.3% to 1% of the boiler capacity.

Such stacks are short, as the height above the throat need not usually exceed 8 times the throat diameter, hence the total height rarely exceeds 60 to 70 ft. and is often much less.

These stacks have been used with success in Europe, South America and elsewhere, but to date few installations have been made in the United States. As they undoubtedly have a field of usefulness wherever local conditions do not compel the delivery of the gases at great heights for sanitary reasons, they should be more extensively used here in the future. Undoubtedly their adoption has been delayed because the technical principles underlying their design have not yet been fully developed, and reliable empirical methods are still lacking. Methods of computing dimensions so far as available may be found in *Combustion,* above cited, and in *Engineering of Power Plants* by Fernald and Orrok.

701. Blanketing Effect of Wind. All the preceding computations assume that stacks are located in the open where they will not be affected by air currents or swirls caused by surrounding buildings, mountains, etc. These may so blanket a stack that a greatly increased height is necessary, but each case must be studied independently, and no reliable general rule can be given.

702. Effect of Air Temperatures on Stack Performance. In the preceding computations we have assumed the external air temperature as 70°, which is somewhere near the mean temperature of the average locality. It is obvious, however, that with different temperatures the stack draft must vary; thus, assuming that the temperature of the stack gas is 500°, then if the outside air is at zero, a stack 100 feet high will produce a total draft of 0.829-inch, whereas if the external air is at 100°, this draft will be only 0.534, which is a drop of 35.6%. Consequently, if a *certain minimum draft has to be insured* at all times, it can be got, when using natural draft, only by figuring the stack height for the highest outside air temperature, or by increasing the temperature of the stack gases, and the latter always represents fuel waste. The former method will usually give a stack height that is prohibitive so that recourse must be had to induced draft.

703. Seasonal Variations in Stack Capacity. The preceding section illustrates how great these may be, but does not show the extremes. In the Northern States of this country, and in Canada, temperatures of 40° below zero Fah. are common, and for weeks or months the thermometer may register 20° below zero. In the summer 100° is not uncommon. At the lower temperatures the draft will be over 80% greater than at the higher temperatures, and this is a tremendous variation which cannot be overcome as long as natural draft alone is used. Therefore, a plant so operated can always develop far higher capacity in winter than in summer. This fact clearly illustrates the futility of evolving long, complicated and tedious stack formulas based on some assumed set of averages for the factors, because a change in air temperature alone nullifies the whole case. It is for this reason that in the preceding exposition care has been taken to work on the "Safety first" principle, therefore the frictional losses assumed have always been ample, and the same is true of other factors.

704. Effect of Humidity on Stack Draft. E. A. Dehling, quoted in *Finding and Stopping Waste in Modern Boiler Rooms,* p. 129, states:—"Draft is better in clear, dry weather than in hot, sultry or foggy weather. This is

due to lower barometric pressure in the latter case, and to the fact that the water vapor which displaces air weighs less than air and a larger volume of air is required for given combustion conditions. Besides displacing air, the water vapor absorbs heat and retards combustion in the fuel bed. The variations in the atmosphere rarely occur to the full extent and probably never at the same time, and one condition may neutralize largely the effect of the others."

705. Proper Location for Stacks. It was formerly a common practise to place stacks on the rear of the boiler or setting. This was not very objectionable when boilers were small, stacks were short, and economy of fuel was of secondary importance, but with modern boilers and high stacks this custom should be condemned. Such stacks, though stayed by guy lines, are considerably shaken by the wind, and with the guy line attachment point as a fulcrum, the stack base wabbles around on the damper plate, and unless the latter is firmly anchored it will shift its position, crack the setting, and let in excess air often sufficient in quantity to reduce the draft very considerably. If the damper plate is anchored to the framework supporting the boiler, the latter will be subjected to stresses which will rack it sufficiently to damage the brickwork. It will thus be seen that the common custom of depending wholly upon the brickwork to support the damper box forming the stack base, without the latter being secured to the framework, is an absolute guarantee that the brick setting will become cracked and often seriously shattered. Such construction is never permitted in Kidwell boilers. See Figs. 173 and 174.

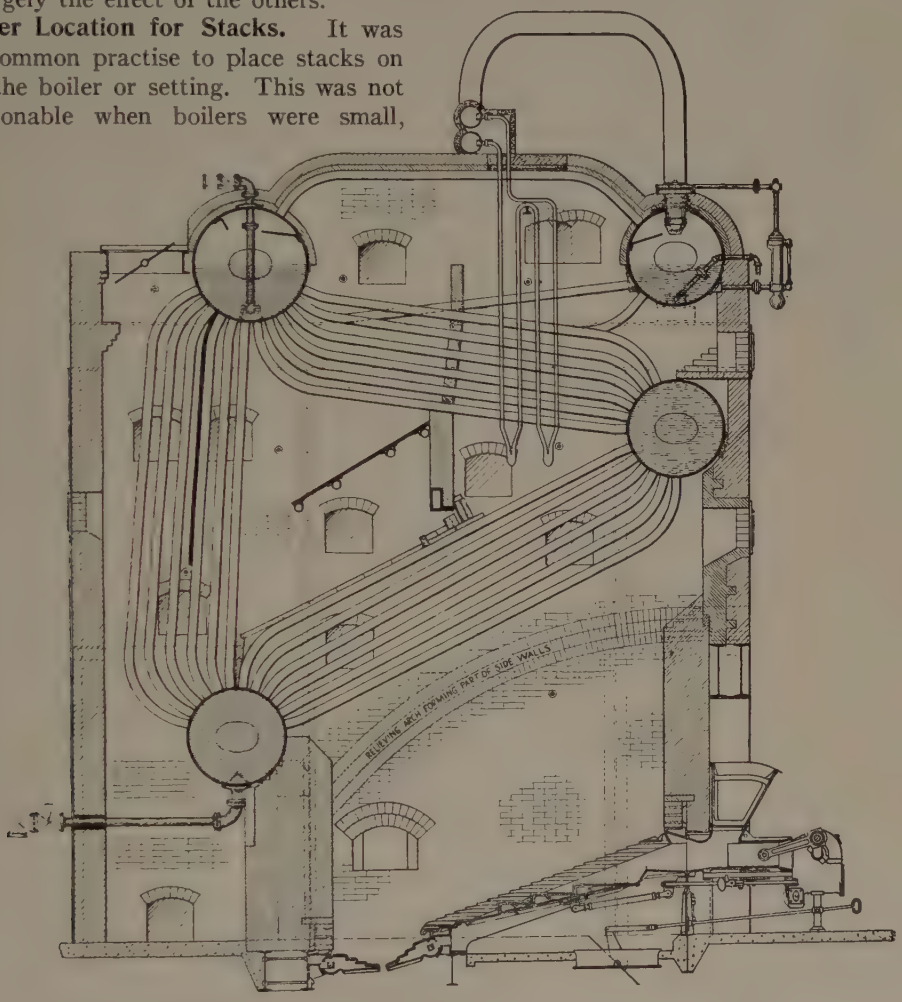


FIG. 205. KIDWELL BOILER, FREDERICK STOKER, AND ELESCO SUPERHEATER

706. Suppose the stack is erected on a cold day, and the guy lines then drawn up fairly taut, and securely anchored. When the boiler is fired up, the length of stack between base and point of attachment of the guy lines may expand 1½ inches, or even more. This at once causes a severe tension in the guy lines, and the reaction

comes upon the stack base, hence when this is supported wholly by the boiler setting the latter will usually be crushed, especially when wind is swaying the stack. If the stress cannot be relieved that way, then either the guy lines will break, or the anchorage be pulled out, and the latter frequently happens. To avoid this, the guy lines have to be left slack, in which case the stack base will surely wabble when the wind blows. When the stack base is anchored to the boiler framework, the pressure brought upon the latter by the expansion of the stack and tight guy lines may cause the framework columns to buckle, hence the scheme of supporting a stack in this manner is to be severely condemned. The stack should rest on an independent base, and be connected to the boiler by a breeching made as short as possible. While this costs somewhat more than the other method, *it is the only way to insure tight stacks and settings,* and every dollar saved by the cheaper method is quickly lost, and this loss keeps right on as long as the plant operates.

707. Stack Covers. An important detail, conspicuous by its absence where most needed, is a chimney cover. In all cases where boilers are liable to be shut down for any time other than for repairs, means should be provided for covering the stack to keep out rain. This is even more important with a steel stack than one of brick, and most important of all for stacks supported directly over the boilers, and so arranged that rain can during a shut-down run directly on to the boiler surface. With any fuel containing sulphur, as common with coal or fuel oil, this will deposit on the stack surfaces, and when rain is admitted sulphuric acid may form, so that both stack and any boiler surface touched by the incoming water will corrode very rapidly. Deposits of soot become actively corrosive when wet. Cases have been known where from these very causes, boilers in sugar factories, closed down at end of the campaign, and with stacks uncovered, have been so badly corroded during one season that a large portion of the tubes had to be replaced.

In the Navies of several countries the regulations as to covering stacks when not in use are very strict, and for this purpose heavy canvas covers have been found very satisfactory.

708. Iron or Steel Versus Masonry Stacks. In normal times steel stacks are usually cheaper than those of masonry, but their life is comparatively short, particularly if the fuel contains much sulphur, or the plant is sufficiently near the sea to be influenced by salt air, which hastens the corrosion of the metal. At the present time (January, 1923) the cost of steel is so high that radial brick or concrete stacks 5 feet in diameter or larger are usually cheaper to build than steel, hence owing to their greater durability they should be preferred. In any case, for a *permanent plant* they will certainly be the cheaper in the long run.

709. General Summary as to Stacks. A stack of proper capacity is as necessary to successful boiler operation as fuel. Any deficiency in the stack not only lowers the fuel efficiency, but to a greater degree it reduces the possible capacity. The number of factors entering the problem of boiler design is so great and these fluctuate over such a range that there is no exact method of determining stack dimensions, and recourse has be made to empirical methods. Such methods lead to erroneous or even absurd results unless applied with good judgment and full understanding of how they were derived, and the limits within which they apply. It is therefore unsafe to depend on any published tables of stack sizes other than as suggestions to be later verified by careful computation.

Regardless of the method used, there will be a discrepancy in results as compared with those got by other methods. This is immaterial if the difference is not great, because the seasonal variations in capacity will be far greater as shown in Sect. 703, hence the important factor is to make the stack dimensions sufficient to prevent distress under the most adverse conditions which the plant may have to meet. The methods of computing stack dimensions as given in this book are based on this principle, and if followed they will prove adequate and protect the boiler owner from disappointment.

A good stoker can operate on less than 18 lbs. of air per pound of coal, but it is poor policy to figure on less when designing a stack, because the stoker may get out of order and not function well, or bad coal have to be used occasionally, etc. *Some excess capacity acts as insurance,* and is often useful, but a shortage cannot usually be overcome.

710. Finally, with the stack as with the boiler, the time to save money is *right at the start, and the way to do it is to spend enough money at the beginning to get both a stack and a boiler of the kind and capacity that will permit operating under high ratings with ease and efficiency,* and thus save money for the owner every hour during the operating life of the plant.

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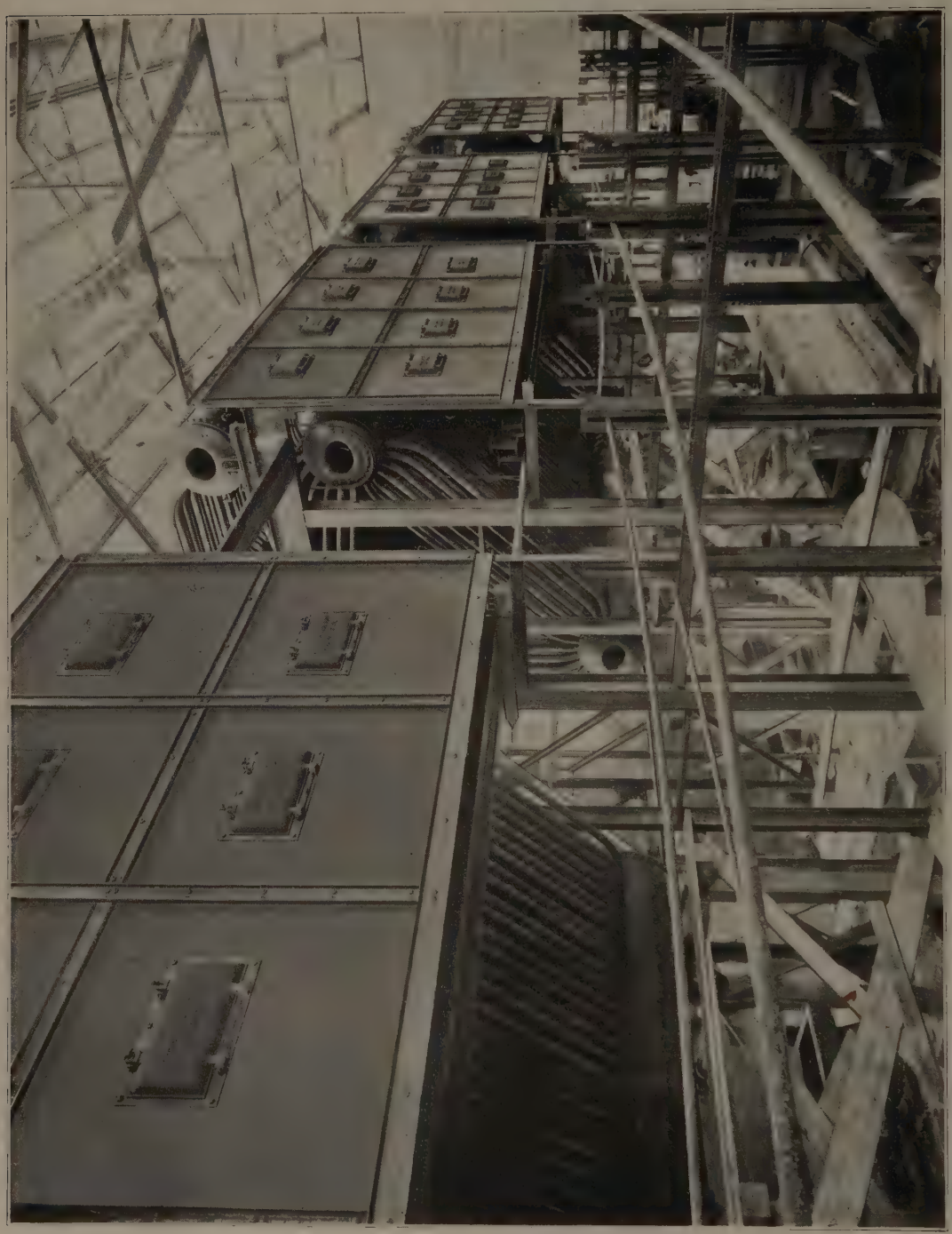

FOUR 752 HP. KIDWELL BOILERS FOR SUGAR PINE LUMBER CO., FRESNO, CALIFORNIA, ARRANGED FOR BURNING HOGGED FUEL AS SHOWN IN DRAWING ON PAGE 203

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CAREFUL AND PROPER PACKING FOR SHIPMENT IS AS ESSENTIAL AS GOOD WORKMANSHIP. NOTE THE CAREFUL PACKING IN ABOVE CUT SHOWING PART OF A SHIPMENT TO CALIFORNIA